The potential of Quality Function Deployment (QFD) in reducing work-related musculoskeletal disorders

The potential of Quality Function Deployment (QFD) in reducing work-related musculoskeletal disorders

by

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Certificate of originality

This is to certify that I am responsible for the work submitted in this thesis, that the original work is my own except as specified in acknowledgements or in footnotes, and that neither the thesis nor the original work contained therein has been submitted to this or any other institution for a degree.

……………………………………………………… (Signed)

……………………………………………………… (Date)

Dedicated to my parents and teachers

දුන්නිග්ගහස්ස ලහුනො - යත්ථ කාමනිපාතිනො
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ධම්මපදය (චිත්තවග්ගය)

English translation:

> *"Wonderful, indeed, it is to subdue the mind, so difficult to subdue, ever swift, and seizing whatever it desires. A tamed mind brings happiness."*
>
> *"Let the discerning man guard the mind, so difficult to detect and extremely subtle, seizing whatever it desires. A guarded mind brings happiness."*
>
> *"Dwelling in the cave (of the heart), the mind, without form, wanders far and alone. Those who subdue this mind are liberated from all bonds."*
>
> Gouthama Buddha (563-483 BCE)

Adapted from: Cittavagga: The mind (Dhamma pada III). Translated from the Pali scripts by Ãcharya (Dr) Buddharakkhita. Access to Insight, June 7, 2009. Available online at: http://www.accesstoinsight.org/tipitaka/kn/dhp/dhp.03.budd.html. [Accessed: 12th January 2010]

Abstract

Musculoskeletal disorders (MSDs) frequently affect the health and well-being of workers and can hinder growth in the industrial sector. Research indicates that user requirements to reduce workplace risk factors for MSDs are not always effectively conveyed to practitioners of design. This creates a mismatch between these requirements and what is ultimately produced. Quality function deployment (QFD) is a structured collaborative design approach, widely used in industry. The aim of this research was to explore the potential of a QFD-based design tool to enhance such communication in the design process and help reduce work-related MSDs.

In order to evaluate user knowledge and ability to identify workplace risks and the subsequent requirements for design, a multi-methods study was undertaken with cleaners (n= 10), joiners (n= 6) and plumbers (n= 6) and their line managers (n= 6). Methods included semi-structured interviews, task analysis, REBA and body part discomfort maps. The findings revealed that these workers were in general able to identify risks to their musculoskeletal health and make design suggestions related to specific tasks. All of the workers expressed concern about manual handling, and issues related to awkward postures were also identified by the majority.

A QFD-based design tool (with guidance material) was then developed to facilitate communication in the design process. It consisted of six features to encompass the design process, and included tools and techniques with supplementary templates to aid practitioners. In order to evaluate its feasibility with respect to current practice, an online questionnaire survey was conducted with a cohort of practitioners of ergonomics and design (n= 32). Of these, the majority rated highly the importance of an integrated approach for participatory design to help reduce work-related MSDs. They also suggested elements to be included in the design tool, which were in congruence with the features already included. To evaluate the strengths and weaknesses of the design tool in the field setting, in-depth interviews using a walkthrough approach (n= 8) and case studies of specific work tasks (n= 3) were conducted with practitioners. The findings showed that the design tool would be very useful in managing and presenting design information. In particular, practitioners liked being provided with design principles to help systematically identify design solutions to reduce risks and using the QFD-based matrices to present such information. Limitations of the tool were identified as inadequacy of guidance, the lack of automated procedures and the time required to set up and learn. The design tool (and guidance material) seems to have potential in facilitating the sharing of design information among the stakeholders of the design process.

Acknowledgements

First and foremost, the precious contribution of my supervisor, Dr. Diane E. Gyi, must be appreciated. This research would not have been possible if not for her acceptance of my application and arranging partial funding in the first place. Her untiring efforts in guiding me to look into things with a critical eye and providing intuitive ideas along the way were invaluable in moulding this research into a fruitful endeavour. She read and corrected numerous drafts of work, tolerated my stupid mistakes and devoted long hours whenever I needed. Diane, you know the art of giving autonomy to the student and maintaining control at the same time. Thank you. You always offered me the best!

Neil J. Mansfield, as my director of research also provided me with valuable guidance. He was instrumental in helping me avoid possible pitfalls in research, especially during the initial vulnerable period. Discussions with him always helped me chase away all the fears that were lurking in my mind. In addition, members of the staff allowed me to audit course modules that they taught accepting my requests without hesitation. It was indeed helpful because I started this research having a background in engineering and was alien to most of the material encountered during my research.

The help rendered to me by the non-academic staff of the Department of Human Sciences (Ergonomics) is also gratefully acknowledged. Their assistance towards initially finding my way in the department and later providing me with facilities whenever I requested without any delay, at times with very short notice, needs special mention.

This account would not be complete if I do not render my gratitude to the participants of the studies. I would have been in considerable trouble if not for the line managers of the organisations and the workers that offered to take part in my studies when I desperately needed participants. Then, the involvement of practitioners, who are always extremely busy, must be commended. They accommodated my requests despite their hectic work schedules and helped me immensely throughout the research. I must also thank everyone that introduced me to the participating organisations and practitioners. In particular, I am grateful to my friend Dr. Anne Fernando for helping me to arrange a study at a time I was desperately looking for places to conduct case studies.

I am extremely fortunate to have come to the UK for my research with my lovely wife, Inoka. It was indeed a consolation to have her with me throughout. Her roles as a friend and as a colleague gave me courage. She was truly a comforting factor whenever I was feeling stressed or depressed. She stood by me like a shadow and complemented my efforts. She also made sure that we had meals on our plates on time. In addition, I take this opportunity to thank my parents, my brothers and their families, relatives and friends back home for letting me get away from my responsibilities towards them during the past four years. This would not have been a smooth time span if not for their support.

It would not be correct if I do not thank the colleagues at my department, and especially, the wonderful friends at my office (Wavy top GG 1.04). I wholeheartedly appreciate their company and support in numerous ways. Being the only male among seven lovely girls, all depressions and frustrations just vanished every time I stepped into the office: It was indeed *human factors!* I am particularly grateful to Manpreet Bains, who obtained her doctorate recently, for kindly offering me to proof read my Chapters despite work at her new workplace. I know, proof reading is always a laborious task!

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Himan Punchihewa

Publications and awards

Parts of this thesis have been published in journals and international conferences.

Journal papers

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Conference papers

Punchihewa, H.K.G. and Gyi, D.E. (2008). Development of a QFD-based approach to collaborative design to reduce work-related musculoskeletal disorders (Extended abstract). *Third International Conference on Design Principles and Practices. Berlin, Germany. 15-17 February, 2009*. Available at: http://g09.cgpublisher.com/proposals/166/index_html [Accessed: 3rd October 2008]

Punchihewa, H.K.G. and Gyi, D.E. (2008). A collaborative design approach to preventing work-related musculoskeletal disorders. In: Bust, P.D. (ed.). *Contemporary Ergonomics 2008*. Taylor and Francis. London. pp 411-416.

Awards

Graduate Student Assistantship award by Common Ground Publishing LLC, Australia to cover registration for the *Third International Conference on Design Principles and Practices. Berlin, Germany. 15-17 February, 2009*.

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PhD studentship (Competitive grant- for living expenses) from the World Bank funded project “Improving Relevance and Quality of Undergraduate Education” (IRQUE): Department of Mechanical Engineering, University of Moratuwa, Sri Lanka.

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1. Introduction

1.1. Context

Work-related musculoskeletal disorders (MSDs) affect the health and well-being of workers and can hinder the growth of the industrial sector causing staggering expenses (Sandell and Kleiner, 2001; Fayad et al., 2003; Vaughn-Miller, 2003; Buckle, 2005; European Agency for Safety and Health at Work, 2007a). In the UK, MSDs account for an estimated 38 per cent of all work-related illnesses and injuries (HSE, 2008). According to estimates of the HSE (2008) calculated using data from the labour force survey, in the UK, from 2002 to 2007, the prevalence of work-related MSDs had been over one million but now appears to have reached a plateau (Figure 1.1).

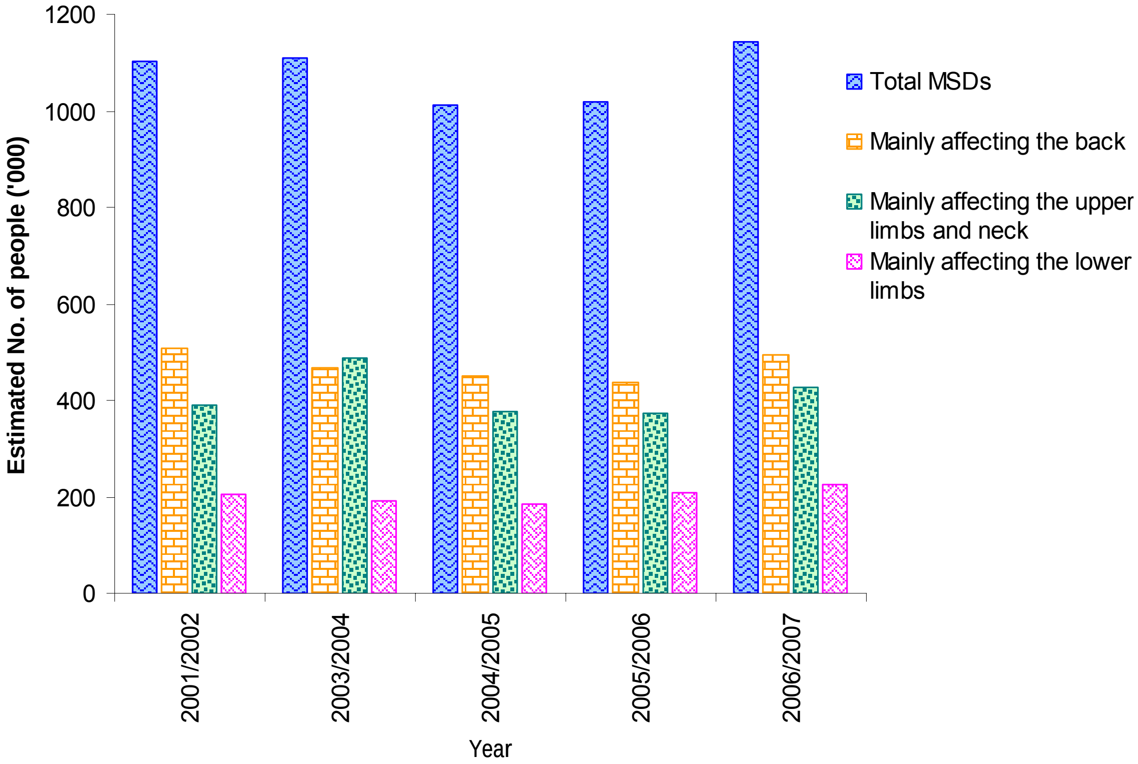


Figure 1.1. Estimated prevalence of MSDs in the UK [source HSE (2008)]

MSDs also account for approximately 60 per cent of all occupational injuries or illnesses in the USA (Sandell and Kleiner, 2001; Vaughn-Miller, 2003; Roh, 2003). The problem is not only confined to the UK and the USA, a similar situation prevails in other developed nations (Gauthy, 2005; European Agency for Safety and Health at Work, 2007b). Where developing countries are concerned, research indicates that there is a rising trend of work-related MSDs (Choi, 2005).

Furthermore, the average age of the working population is increasing worldwide and is likely to pose an additional burden on the issue of work-related MSDs (Barth, 2000; Amell and Kumar, 2001; Walters, 2001). As a result of health risks and related costs, recognition and control of work-related MSDs has become a major concern (Melhorn, 1996; Cole et al., 2006; Burton et al., 2009). Hence, prevention or at least, reduction in work-related MSDs is an important priority.

Attempts have been made in the past to reduce the prevalence of MSDs among the working population. A plethora of intervention programmes (e.g. Haines et al., 2002; Kogi, 2008; Zink et al., 2008), standards (e.g. Karwowski, 2006) and guidelines (e.g. NIOSH, 2007; OHSCO, 2007; 2008) have been developed to try to eliminate workplace risk factors. These may have accounted for the slight decrease in work-related MSDs in recent times, but researchers (e.g. Pransky et al., 1999; Amell and Kumar, 2001; Rosenman et al., 2006) argue that this apparent reduction might be due to errors in sampling as, often, only severe cases of MSDs are reported. The fact remains that work-related MSDs are commonplace and further research is necessary in order to provide safe working conditions for workers.

Research suggests that more intervention activities are required and that methods currently being used to reduce the risk of MSDs among workers could be improved (Vink et al., 1992; Kogi, 2002; 2006). Neumann et al. (2009) have also suggested integrating ergonomics into system design as a research priority. Buckle (2005) identifies system goals, task allocation, equipment design, man-machine interaction, work organisation and job design as ways of reducing work-related MSDs. This author reiterates that greater adherence to ergonomics in the design and assessment of work systems would help curb work-related MSDs emphasising the importance of design as a means of reducing work-related MSDs. Mital (1995) advocates research pertinent to design focusing on human factors and manufacturing. Amell and Kumar (2001) and more recently Karwowski (2005) also believe design is important in the prevention of work-related MSDs. Although the importance of design in reducing MSDs has been identified, Karwowski (2005) points to the need for research into investigating ways of helping practitioners in design.

A drawback in the design process is the mismatch between user requirements and what is ultimately produced (Slappendel, 1994; Shinnar et al., 2004; Broberg, 2007a). Stakeholders in the design process include users that directly interact with equipment and processes that give rise to workplace risk factors for MSDs and practitioners such as engineers, designers and others (e.g. ergonomists, occupational health professionals, and health and safety personnel) that take part in the design process influencing design decisions. However, their involvement in the design process varies (Vink et al., 2008). Therefore, user requirements to reduce workplace risk factors for MSDs are not always effectively and efficiently conveyed to the practitioners of design creating this mismatch between user requirements and what is produced.

To complicate matters, there may be a possibility that user requirements related to the reduction of MSDs may be incomprehensible even to the users that directly interact with the equipment and processes. In other words, the users' perspective is not fully understood by the practitioners of design, and vice versa. This gap in the communication process prevents appropriate design solutions from being incorporated in the next generation of designs to reduce MSDs. Thus, a mechanism to fill this void between the users and the practitioners of design may lead to a better understanding of the user requirements that would potentially reduce work-related MSDs.

Quality function deployment (QFD) is a user-centred and structured collaborative design approach that has been widely used in industry since its inception in the late 1960's (Chan and Wu, 2002). Deriving requirements from the users themselves is one of the key features of QFD. It emphasises the importance of being aware of the exact problems experienced by workers for effective design. As Yoshizawa (1997) states (cited by: Akao and Mazur, 2003), "*QFD has provided a communication tool for designers. Engineers, positioned midway between marketing and production, need to take a leadership role in new product development. QFD is a powerful tool for engineers to build a system for product development*".

Given the wide range of applications of QFD, it was of interest to the author to investigate its feasibility as the basis to develop a design tool for practitioners that are involved in reduction of work-related MSDs to enhance communication in the design process. An approach based on a participatory model that engages key stakeholders is advocated by Buckle (2005) as he considers it important to formulate work-related MSD prevention measures. A similar approach is also recommended by Mital (1995). Dul et al. (2003) suggest a similar model where managers, designers, ergonomists and users are involved in collaboration to develop ergonomics standards to help reduce work-related MSDs.

Interestingly, there are limited instances where QFD has been used in ergonomics (Bergquist and Abeysekera, 1996; Marsot, 2005; Kuijt-Evers et al., 2009). These authors hint about the potential of QFD as an approach for participatory ergonomics, but many researchers find it inherently complex (Franceschini and Rossetto, 1998; Iranmanesh et al., 2005; Gonçalves-Coelho et al., 2005; Cheng et al., 2003). Hence, suitable modifications and methods to simplify and supplement QFD need to be investigated to reduce its complexity and to facilitate communication as part of a design tool to help minimise workplace risk factors for developing work-related MSDs.

1.2. Aim and objectives

The aim of the research was to explore the potential of a QFD-based design tool to enhance communication between the workers (users) and practitioners of design in the process of determining design solutions, and help reduce workplace risk factors for developing MSDs. Involving users in the design process is likely to be effective, and the reduction of work-related MSDs may in turn save labour hours and reduce related costs, which in the long term, will lead to increased productivity.

In this pursuit, the following objectives were considered.

1. To evaluate user knowledge and ability to identify workplace risks and the subsequent requirements for design in order to reduce the risk factors for developing MSDs;

2. To develop a QFD-based design tool to facilitate communication in the design process to help reduce work-related MSDs;

3. To evaluate the feasibility of the design tool with respect to current practice;

4. To evaluate the strengths and weaknesses of the design tool in the field setting and make recommendations for using QFD in this context.

1.3. Methodology

From a methodological point of view, this research was inclined towards a post-positivist approach (qualitative) rather than a positivist (quantitative) approach. Multiple methods were used with small samples (Crossan, 2003) with a view to understanding the situation under examination. According to the “research onion” shown in Figure 1.2 (Saunders et al., 2007), this research is placed as one that uses a cross-sectional and multi-method approach whereby survey techniques and case studies are used to induce knowledge from the participants and situations. A pragmatic (ideology or proposition is true if it works satisfactorily) philosophical view was adopted for data collection and analysis. Within this methodology, initially a literature survey was carried out. Subsequent to this, a study was carried out to evaluate the user knowledge and ability to identify workplace risks and the subsequent requirements for design (Objective 1). This was followed by the development of the QFD-based design tool to facilitate communication among the stakeholders that are involved in the design process (Objective 2). A questionnaire survey was then conducted with a cohort of practitioners involved in design pertinent to reduction of MSDs to evaluate its feasibility with respect to current practice (Objective 3). Finally, the prototype tool was subjected to in-depth evaluation (Objective 4) by way of practitioner interviews and case studies in the industrial setting. A brief overview is given in Sections 1.3.1 to 1.3.5. The thesis concludes by providing an overall discussion of the research and drawing recommendations for practice.

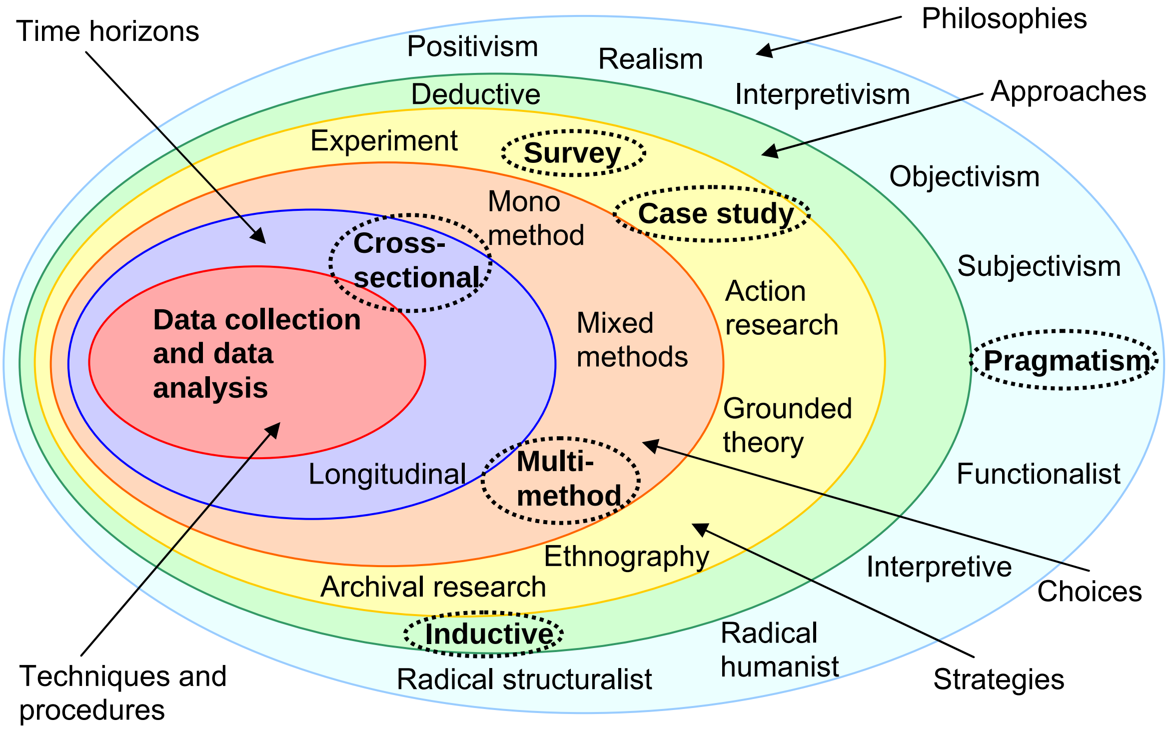


Figure 1.2. The research plan according to the 'research onion' [adapted from Saunders et al. (2007)]

1.3.1. Literature review

A comprehensive literature survey was conducted employing a hierarchical approach using the academic information system of Loughborough University, which is linked to various catalogues and online resources. Initially, a keyword (i.e. musculoskeletal disorders- MSDs; work-related MSDs; ergonomics and design and design methodologies) search was conducted. While reading relevant literature, citations within publications were searched to access further relevant publications. Only literature available in English was included in the search, and translations were searched whenever a publication was accessed in other languages. Both printed and electronic publications were accessed, and included books, journals, theses, reports, databases and magazines. The literature review led to the understanding of the subject area and gaps in knowledge, and subsequently helped identify information, tools and techniques that could be utilised in the research.

1.3.2. User requirements study

The first study was undertaken to investigate potential worker involvement in a participatory process by evaluating their knowledge and ability to identify workplace risks and the subsequent requirements for design in order to reduce the risk factors for developing MSDs (Objective 1). Data were collected from three case study areas that included diverse work tasks. Information was gathered from workers through semi-structured interviews and observations. Workers' line managers were also interviewed. The findings showed that the workers (users) were in general able to identify risks and specify user requirements to help reduce workplace risk factors for developing MSDs. The tools used for data collection were fed into the development of the design tool.

1.3.3. Development of the design tool

In order to facilitate communication among the stakeholders involved in the design process to help reduce work-related MSDs, a QFD-based design tool was developed (Objective 2). Potential stakeholders include users (workers), practitioners of design (e.g. designers and engineers) and other practitioners (e.g. ergonomists, human factors engineers, occupational health practitioners, and health and safety personnel). After extensive research, it was decided that the design tool would consist of features to encompass phases of the design process from 'assessment of workplace risk factors for developing MSD' to 'presentation of design information'. The prototype tool was developed with guidance material, and suggested supplementary methods and tools to help the practitioners involved in the design process to help reduce work-related MSDs.

1.3.4. Feasibility of the design tool

In order to evaluate the feasibility of the design tool with respect to current practice (Objective 3), a questionnaire survey (online) was conducted with practitioners (e.g. ergonomists and designers) that were involved in trying to reduce work-related MSDs. Practitioner requirements identified through the findings from the questionnaire and the contents of the developed design tool were compared to assess the feasibility and potential of the tool. The study helped verify the methods and tools that were included in the guidance material and specific design information that needs to be presented.

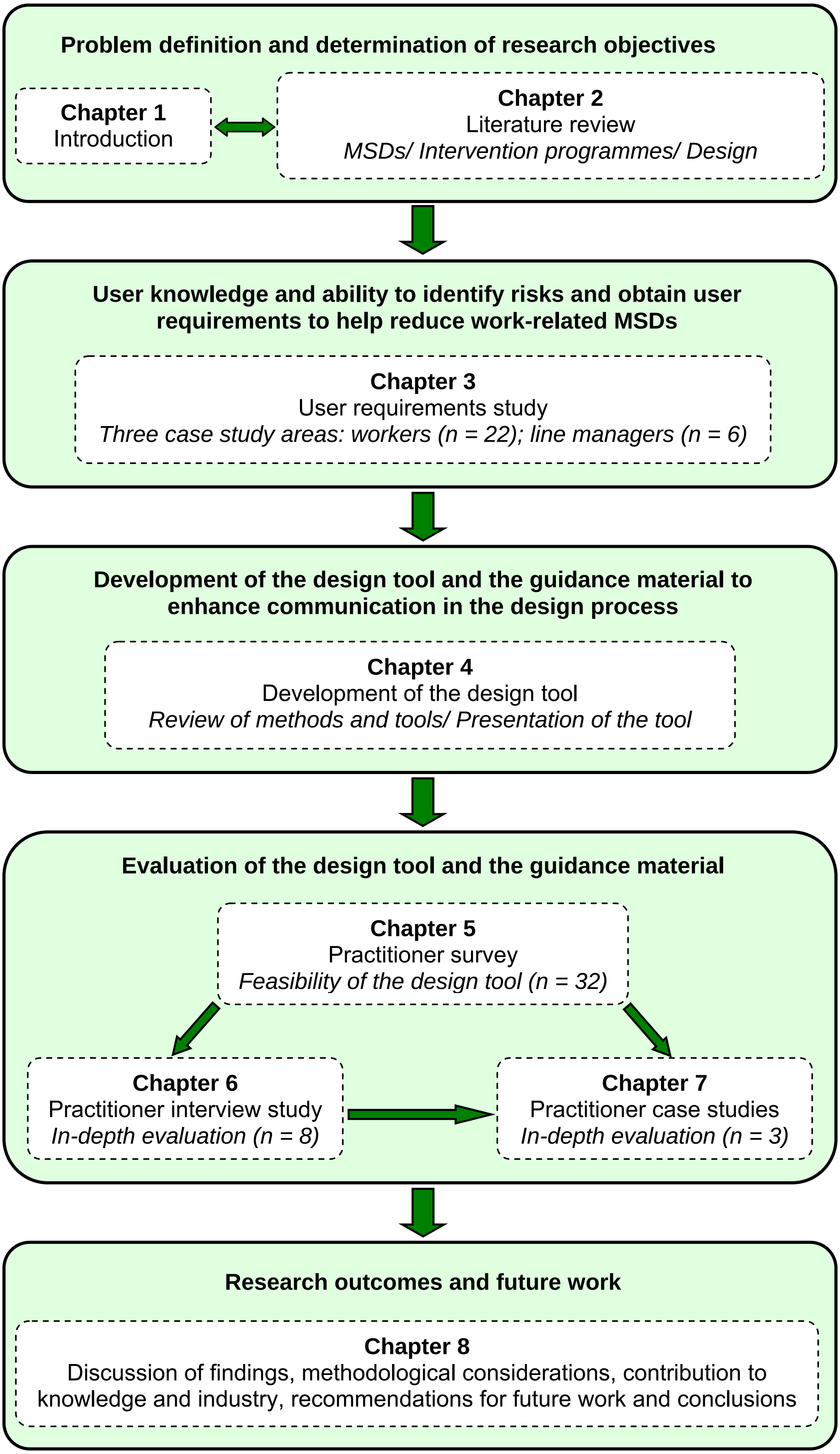
1.3.5. Evaluation of the design tool

Further research involving practitioners was conducted comprising interviews and case studies in order to evaluate the strengths and weaknesses of the design tool in the field setting (Objective 4). Initially, in-depth interviews were conducted with a subset of practitioners that responded to the questionnaire survey to identify the feasibility (in terms of capabilities, limitations and the scope for future development) of the design tool. The design tool was partially refined using the findings of this study. Following this, case studies were carried out by putting the design tool into use in the field setting to obtain a more in-depth evaluation of the tool in terms of usability, capabilities and limitations. Results of this study were also used to identify directions for future development of the design tool and recommendations for its use.

1.4. Organisation of the thesis

The thesis is organised as follows using a hierarchical structure. Initially, the literature review is presented to provide background information related to the research (refer Chapter 2). This is followed by a discussion of the user requirements study (refer Chapter 3). Chapter 4 elaborates on the development of the QFD-based collaborative design tool and its guidance material for practitioners. The prototype design tool is presented at the end of this chapter. Then, Chapter 5 describes the findings from the practitioner survey. After that, Chapter 6 presents an evaluation of the prototype design tool based on in-depth interviews with the practitioners. In addition, the limited modifications carried out in the tool are listed. Chapter 7 elucidates the practitioner case studies that were carried out to evaluate the design tool (and its guidance material) by putting it into practice. Finally, Chapter 8 provides a discussion of the findings of the entire thesis together with methodological considerations of the research, the contribution to knowledge, relevance to industry and recommendations for future work. Conclusions are drawn at the end of this chapter.

Structure of the thesis



2. Literature review

2.1. Introduction

This chapter provides the reader with a broad understanding of the research area with regard to the existing body of knowledge. Although the central focus of the thesis is developing a tool for practitioners (e.g. designers, engineers, ergonomists and health and safety personnel) to enhance communication in the design process to reduce work-related MSDs, it is important to gain an understanding of the context of this with respect to related literature. In addition, review of the approaches used and approaches that could be adopted/adapted to help achieve the research objectives are vital. The objectives of the literature review were:

- To understand the research focus in the context of reducing MSDs;
- To evaluate approaches to facilitate the communication of design information.

2.2. Review strategy

The literature survey was conducted using a hierarchical approach. Initially, a title-based keyword search (i.e. musculoskeletal disorders- MSDs; work-related MSDs; reducing work-related MSDs and design methodologies) was conducted. Citations within publications were also examined for further relevant publications, and specific searches were conducted based on related terminology used within the accessed literature. These extended searches used keywords such as repetitive strain injuries (RSI), cumulative trauma disorders (CTD) and occupational cervicobrachial disorders (OCD) as they were used in the literature, at times, synonymously with work-related MSDs.

The academic information system of Loughborough University (Metalib), which is linked to various catalogues and online databases such as Illumina, Ergonomics Abstracts, ArticleFirst, Compendex, Web of Science, Occupational Health and Safety Information Services and Zetoc, was used to access information. In addition, web based journal publishers such as Sage, Science Direct, Springer, Ingenta, Informaworld, Taylor and Francis, Indescience and Elsevier were directly accessed as necessary. Google scholar web tool was also used as a quick search tool to look for relevant articles. Furthermore, information on ergonomics, occupational medicine, safety, physiology, engineering and industrial design and research methods were accessed using sources from both UK and other government authorities and professional institutions. Both printed and electronic publications were accessed, which included books, journals, theses, reports, databases and magazines. Only the literature available in English was included in the search, and translations were searched whenever a relevant publication written in a different language was accessed.

2.3. Defining MSDs

Several definitions for MSDs are to be seen in the literature depending on risk factors and affected parts of the body, but there seems to be no common agreement regarding these definitions between researchers from different disciplines (Diwaker and Stothard, 1995; Buchbinder et al., 1996). The terms used also vary in different parts of the world (Buchbinder et al., 1996). The different terminologies and definitions are listed in Table 2.1.

According to these definitions, MSDs are clearly discomfort, disorders or pain in the locomotor apparatus caused by injury due to repeated use of tissues and, discomfort, disorders or pain due to accidental damage to the tissues are not considered as MSDs. Such conditions that are caused by single incidents are known as acute traumatic injuries (MIT, 2005) or single event injuries (Kroemer, 1989).

Table 2.1. Definitions of musculoskeletal disorders (MSDs)

Term	Definition
MSD	• Cover a wide variety of phenomena and experiences (discomfort, disorders and pain). They are not accidents, but injuries to joints, muscles, ligaments, tendons, peripheral vessels or nerves (Gouthy, 2005) • Health problems of the locomotor apparatus that includes muscles, tendons, the skeleton, cartilage, ligaments and nerves. These encompass all forms of ill-health ranging from light, transitory disorders to irreversible, disabling injuries (Luttmann et al., 2003) • Repeated trauma to muscles, tendons and peripheral nerves (Rosecrance and Cook, 1998)
Work-related MSD (also known as WRMSD)	• Ailments which are induced or aggravated by work, and the circumstances of its performance (Luttmann et al., 2003) • A wide range of inflammatory and degenerative diseases and

Term	Definition
	disorders. These conditions result in pain and functional impairment, and may affect the neck, shoulders, elbows, forearms, wrists and hands (Buckle and Devereux, 2002)
Occupational MSD	• Used synonymously with work-related MSDs (Rosecrance and Cook, 1998)
CTD	• Injuries of the neck and upper extremities (Luttmann et al., 2003) • An injury mechanism whereby repeated exertions over a period of time contribute to an illness (Muggleton et al., 1999) • Adverse health effects that arise from chronic exposure to micro-trauma (Putz-Anderson 1988- cited by Rosecrance and Cook, 1998) • Physical injuries which develop over a period of time as a result of repeated biomechanical or physiological stresses on a specific body part (Fernandez, 1995) • Injuries sustained through often repeated actions whose cumulative effects finally result in an injury (Kroemer, 1989) • Collective term for syndromes characterized by discomfort, impairment, disability or persistent pain in joints, muscles, tendons and other soft tissues, with or without physical manifestations (Kroemer, 1989)
RSI	• An umbrella diagnosis for a variety of musculoskeletal disorders that cause physical symptoms in people who conduct the same motor action repeatedly and over extended periods of time (Rietveld et al., 2007) • Injuries involving damage to muscles, tendons and nerves caused by overuse or misuse. They most commonly affect the hands, wrists, elbows, arms, shoulders, back or neck (MIT, 2005) • Injuries of the neck and upper extremities (Luttmann et al., 2003) • Injuries caused or aggravated by repetitive or sustained sub-

Term	Definition
	maximal exertion of the body's soft tissue structures including muscles, tendons, ligaments and nerves (Schwartz, 1992- cited by O'Neil et al., 2001) • Disturbance in the balance between load and physical capacity, preceded by activities that involve repeated movements or prolonged periods spent with one or more of the relevant body parts in a fixed position (Luttmann et al., 2003) • Conditions where muscles are kept tensed for long periods of time due to work situations and the tasks performed, along with frequency, duration of exposure and forces or vibrations experienced governed by poor posture and/or repetitive motions (Westgaard, 2000; O'Neil et al., 2001) • Medical syndrome affecting the neck, upper back, shoulders, upper and lower arms, elbows, wrists or hands, or a combination of these areas (Health Council of the Netherlands, 2000) • A soft tissue disorder caused by overloading of particular muscle groups from repetitive use of constrained postures (Rosecrance and Cook, 1998)
Occupational cervicobrachial disorder (OCD)	• Functional and/or organic disturbance resulting from doing jobs in a fixed position with repetitive movement of the upper extremities (Maeda et al. 1982- cited by Rosecrance and Cook, 1998)
Overuse syndrome	• Conditions that occur because of excessive stress placed on an area of the body (Encarta, 2007) • Persistent pain and tenderness in the muscles and joint ligaments of the upper limbs due to excessive use, and in more advanced instances by weakness and loss of response and control in the affected muscle groups (Fry, 1987)

When the repeated use of tissues that cause MSDs is induced by work activities, they are termed as work-related MSDs or occupational MSDs. Work-related MSDs are not due to accidents, but injuries due to long term effects of work factors to joints, muscles, ligaments, tendons, peripheral vessels or nerves (Gauthy, 2005). As stated in an article by Gauthy (2005), when MSDs to the upper extremity are described by cause, they are referred to as work-related upper limb disorders (WRULD).

According to Table 2.1, there are definitions that attribute CTDs to injuries of the upper extremity (e.g. Health Council of the Netherlands, 2000). Conversely, there are other researchers (e.g. Kroemer, 1989; O'Neil et al., 2001; Luttmann et al., 2003) that attribute CTDs to the whole body. RSI is the most common term currently being used to describe symptoms (Peper et al., 2003). However, Diwaker and Stothard (1995) state that RSI gives rise to ill-defined muscular pains with no physical findings other than muscular tenderness and the associated disability, and has different definitions among different professionals. For example, as mentioned above, conflicting definitions of Health Council of the Netherlands (2000), and Kroemer (1989), O'Neil et al. (2001) and Luttmann et al., 2003) can be considered. Diwaker and Stothard (1995) conclude that the term RSI is ambiguous and should no longer be used. In addition, according to the definitions, CTDs and RSIs could be considered as synonymous with both WRULD and work-related MSDs in general.

Unlike CTDs and RSIs, OCDs do not refer to conditions of any specific body region (Rosecrance and Cook, 1998), thus encompass the whole body. Amell and Kumar (2001) acknowledge that work-related MSDs are frequently referred to by synonyms such as occupational musculoskeletal injuries and illnesses and RSIs. Peper et al. (2003) consider all CTD, RSI, overuse syndrome, WRMSDs and WRULDs as synonymous. As stated in the MIT (2005) website, "*RSI develops slowly over time; thus, they are also called CTDs or MSD*" supporting this notion.

The above discussion shows that there is no agreement among researchers on definitions or related terminology pertinent to musculoskeletal disorders. All conditions (e.g. discomfort, disorders and pain) that affect any part of the body could be conveniently considered as MSDs in general. When MSDs are attributed to work factors, they could be referred to as work-related MSDs. This can be regarded as the most appropriate and convenient way to describe these conditions. No matter what terminology is used, all are conditions which encompass the whole or part of the body. Due to the various terminologies used to describe the same musculoskeletal conditions, the literature review was based on the key words 'MSDs', 'work-related MSDs', 'occupational MSDs', 'CTDs', 'RSI', 'ULDs', 'WRULDs', 'OCD' and 'overuse syndrome'.

Given that there are different definitions of MSDs (Table 2.1), it is worth noting the use of other relevant terms used in these definitions (i.e. ailment, injury, illness or sickness, disease, disorder, syndrome and pain) as again, there is confusion among professions regarding their use. These are also at times used synonymously. Descriptions of these terms are listed in Appendix 2.1. By studying the definitions for disease, disorder and syndrome, it can be postulated that the definition of disease does not involve a cause, but disorders clearly involve one or a set of causes. Syndrome is the outcome of a disease or disorder. When the term ‘pain’ is analysed, it can be considered as a psychological symptom of a disease, disorder or an injury. Supporting this argument, National Research Council and Institute of Medicine (2001) report that pain is the most common symptom for which patients see physicians.

However, a problem that is faced by all professions is the inability to correctly judge or assess the levels (or intensity) of symptoms due to their subjectivity. The National Research Council and Institute of Medicine (2001) describe that “*just as there is wide variability in the nature of the inciting event, there is wide variability among individuals in response to pain and functional limitations including a variety of individual coping mechanisms, the effectiveness, extent and adequacy of personal support systems at home and at work, and the individual's broader adjustment to the work context. These factors mean that injury is a psychosocial event as well as a biological or physical one*”. However, Diwaker and Stothard (1995) state that the use of the term 'injury' for a form of occupational 'disease' is again unfortunate signifying the fact that these two terms have distinct definitions within the medical profession.

When defining MSDs, it can be seen from this review that the field of ergonomics has adopted the terminology used in medicine, i.e. a multifactor problem involving physical, psychological and organisational risks that do not essentially relate to injury or illness [WHO (1985) cited by Amell and Kumar (2001)]. Yet, other terminology is also widely used in literature. Due to the wide variety of definitions and terminology, the literature search was extended to include terms such as ‘ailment’, ‘injury’, ‘disorder’, ‘syndrome’, ‘symptom’, ‘disease’ and ‘pain’ to help identify risk factors for MSDs. Risk factors for injuries due to work-related accidents were excluded from the review as accidents are clearly identified as acute traumatic injuries (Kroemer, 1989).

2.4. Factors influencing MSDs

Van Eerd et al. (2003) advocate that classifications are required for accurate communication, and present a review of classification systems for MSDs. This structure is described as being made up of two components, disorders/syndromes identified within the classification and the criteria required for each disorder/syndrome.

Literature reveals that the names of conditions vary even though the symptoms are similar, and the definition and criteria for diagnosing them also differ (Buchbinder et al., 1996). In addition, as mentioned previously, work-related MSDs are recognised as being multi-factorial. Furthermore, Rissén et al. (2002) and Chen et al. (2005a) suggest that, to date, there is no clear or generally agreed case definition on work-relatedness for musculoskeletal disorders. Therefore, the issue of MSDs can be considered as a complex problem where the notion of causality is often disputed (Rosecrance and Cook, 1998; Sandell and Kleiner, 2001); hence, making it difficult to determine a definite cause and effect relationship for MSDs, symptoms and causes. This makes the task of classification of work-related MSDs and identification of risk factors difficult. Further, literature indicates that there is room for research to establish an accepted classification.

Only high level categorisations of risk factors are present in the literature probably due to the fact that there are interactions or ambiguities among factors observed when trying to subdivide these broad level categories. For example, it is difficult to distinguish between psychosocial factors and stress factors. Thus, they are at times categorised together in literature (Fredriksson et al., 1999; Devereux, 2005). There have been attempts to develop models to explain the causation of MSDs. For example, Marras (2004) explains a comprehensive causation model (Figure 2.1). However, this model looks complicated due to the interactions between the factors influencing MSDs.

Figure 2.2 illustrates a simpler conceptual framework of factors that contribute to work-related MSDs. The tissue responses are a result of the musculoskeletal load influenced by work procedures, temporal exposure factors, equipment and the work environment. These tissue responses result in either adaptation of the body or the appearance of symptoms of MSDs (the outcomes). Symptoms can develop into impairments and later may lead to disability. The outcomes are also influenced by organisational and individual factors and the social context.

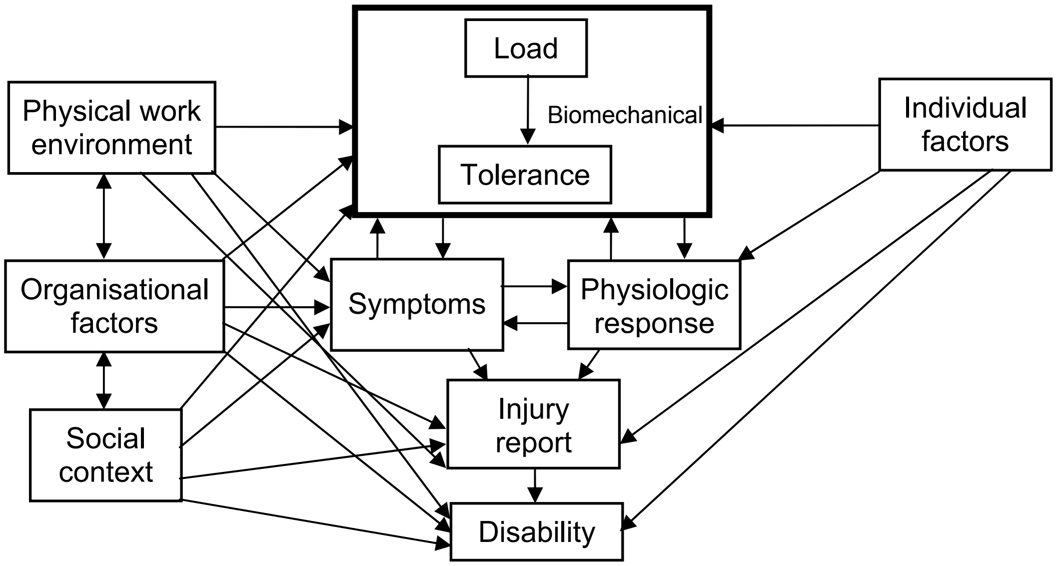


Figure 2.1. A comprehensive MSD causation model (Marras, 2004)

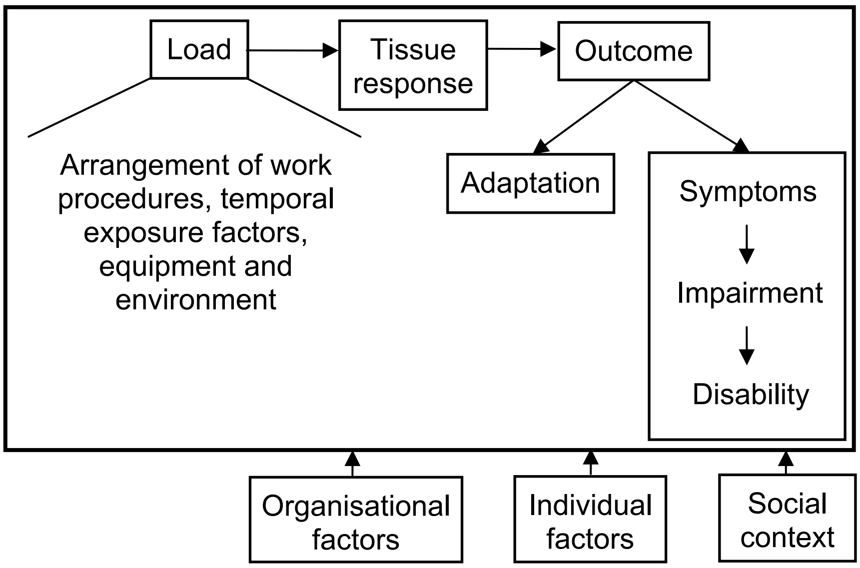


Figure 2.2. Conceptual model of factors that may contribute to MSDs [adapted from Estill et al. (2002)]

According to the classification in Figure 2.2, organisational factors could include the psychosocial environment as well as physical risk factors. Individual factors may depend on the physiological and psychological capabilities and limitations of people. The social context may cover the workers' life both at work and away from work. Other researchers (Westgaard, 2000; Health Council of the Netherlands, 2000; Kumar, 2001; Devereux, 2005) also suggest similar categorisations of factors affecting MSDs. For instance, Westgaard (2000) and Devereux (2005) broadly categorise risk factors for work-related MSDs into three; namely, physical, psychosocial and stress, based on associations of the MSDs with symptoms.

The Health Council of the Netherlands (2000) adds another dimension to this by proposing patho-physiological mechanisms as a risk factor for MSDs indicating that the classifications by researchers are varied. Using this review, a logical categorisation of risk factors influencing MSDs was established to facilitate discussion of the topic, i.e. physical factors, patho-physiological factors and psychosocial factors.

2.4.1. Physical factors

Although the idea of what factors cause MSDs is contested, there is ample evidence to show that MSDs are influenced by physical work factors (Smedley et al., 1995; Ketola, 2004; Kindenberg et al., 2006). Evidence for agreement between occupational physicians and rheumatologists with regard to work-relatedness and MSDs (Chen et al., 2005b) also indicates the influence of physical work factors. Fredriksson et al. (1999) identify physical risk factors as heavy lifting, static work postures, vibration and repetitive jobs. Kilbom (1994a, 1994b) reports that static loads, postures and exertion of external forces affect MSDs. Devereux (2005) identifies high postural load, i.e. the duration of sitting, twisting and bending of the trunk and biomechanical load from a combination of force, posture and repetition as risk factors. Other researchers (Reich and Dear, 1993; Grant et al., 1994; Muggleton et al., 1999; Westgaard, 2000; Health Council of the Netherlands, 2000; HSE, 2007) have also shown that there are associations between MSDs and the physical factors mentioned above. It is also interesting that some researchers (Greening and Lynn, 1988; Muggleton et al., 1999; Kindenberg et al., 2006) are signifying vibration as a potential physical risk factor. However, vibration may also be considered as one extreme of repetitive motion where the frequency of repetition is high (or cycle time is short).

Physical factors can therefore be categorised mainly into force (load), posture and repetition. These are the factors that result in the tissue responses illustrated in Figure 2.2, which need to be addressed in order to provide solutions to reduce work-related MSDs. Strong evidence for the presence of these risk factors in industry and their relevance to MSDs is indicated in the literature (Table 2.2).

The time that one is exposed to physical factors also plays a part in inducing MSDs. Kindenberg et al. (2006) conclude, if the exposure time is high with higher forces, a high number of repetitions or awkward postures, it is evident that workers are more susceptible to MSDs. There is also evidence to show that an association between working hours and physical fatigue exists (Nagashima et al., 2007). Their cross-sectional study involving 715 chemical factory workers shows that physical fatigue significantly increases when people work beyond 280 hours per month.

Table 2.2. Main physical risk factors for work-related MSDs

Factor	Evidence
Force (load)	Forceful exertion of forces and prolonged static loads influence MSDs (Bernard, 1997; Aptel and Cnockaert, 2002; Marras et al., 2009)
Posture	Maintaining extreme postures increases the strain on the affected muscles (Aarås et al., 1997; Aptel and Cnockaert, 2002; Kindenberg et al., 2006).
Repetition	Sandell and Kleiner (2001) cite that more than 60 percent of all workplace injuries are caused by repetitive motion. Repetition has been identified as the factor that has the strongest influence on MSDs (Crumpton et al., 2000). Latko et al. (1999) also identified that repetitive work is related to MSDs. Muggleton et al. (1999) further state that the repetition rate correlates with nerve compression disorders too and a high load is not an essential prerequisite. Ngomo et al. (2008) suggest that there is also an association between static postures (prolonged load bearing) and MSDs.

As mentioned earlier, physical activities outside the workplace (such as the ones derived from domestic responsibilities and physical fitness programs) can also induce musculoskeletal problems affecting the course of disorders incurred due to physical work within the workplace (Moray, 2000; National Research Council and Institute of Medicine, 2001). However, the main factors that influence MSDs (i.e. force, posture, repetition) remain the same.

The confounding effects of workplace physical risk factors and other risk factors such as psychosocial factors make workplace risk assessment more difficult. As discussed previously, the notion of work-relatedness of MSDs has always been controversial and disagreement among different factions of researchers exists. Attributing MSDs to work or occupation without substantial evidence may pose unnecessary constraints on the design process. This is a matter of concern and can be considered as a barrier to providing effective solutions to reduce MSDs among the workers in industry. However, a reduction in the physical factors of exposure has the potential to reduce the prevalence of MSDs. This is discussed in Section 2.4.

2.4.2. Patho-physiological factors

It has already been noted that MSDs affect nerves, bones and soft tissues. During muscle contractions, the tendons are subjected to mechanical stresses, which require recovery time, and when there is insufficient time to recover, inflammation of the tissues gives rise to pathological conditions (Kilbom, 1994a; 1994b). The literature suggests physical deformities or abnormalities, age, gender and build (physique) as the patho-physiological factors that contribute or lead to MSDs.

- Physical deformities or abnormalities: Various pathological mechanisms can give rise to MSD problems. They include abnormalities affecting the muscles, nerves and tendons, separately or in combination (Health Council of the Netherlands, 2000). Disorders of the central nervous system may also lead to MSDs (Health Council of the Netherlands, 2000).
- Age: Previous research shows that the prevalence rate of MSDs varies according to the age of individuals (Figure 2.3), and it is a catalyst for the onset of MSDs (Fernandez, 1995; Barth, 2000; Amell and Kumar, 2001; Walters, 2001). Furthermore, the average age of the working population is increasing across the globe (Barth, 2000; Malatest, 2003; UN, 2006; 2007). This is evident from the comparison of population pyramid for year 2000 and forecasted population pyramid for 2050 (Figure 2.4). Proactive ergonomics approaches could ensure compatibility between the skills and limitations of the aging workforce particularly when taking the design of workplaces into consideration (Kowalski-Trakofler et al., 2005).

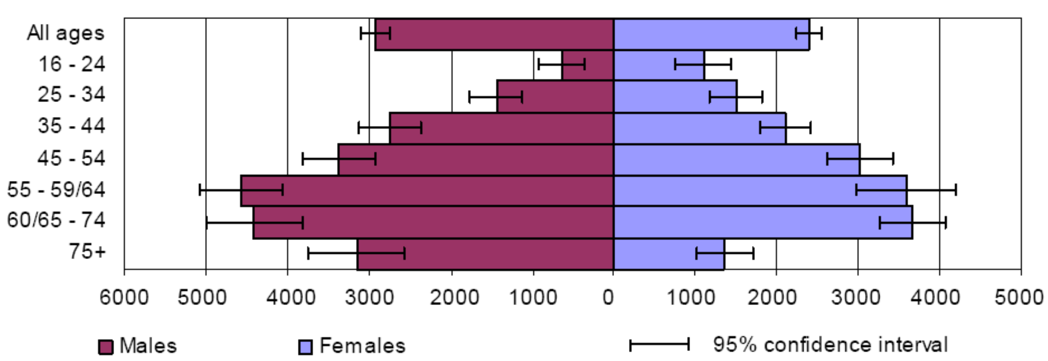


Figure 2.3. Estimated 2006/07 prevalence rates of self-reported musculoskeletal disorders caused or made worse by work, by age and gender, per 100 000 people ever employed (HSE, 2008)

- Gender: Prevalence rates of MSDs are higher in females than in males (Tanaka et al., 2001; Vroman and MacRae, 2001; Treaster and Burr, 2004; Dahlberg et al., 2004). This is evident in Figure 2.3. A review by Punnett and Herbert (2000) discusses that women report MSDs more than males, but they suggest further research is needed to ascertain whether MSD risk varies according to gender. Leijon et al. (2005) also agree that more research is needed in this area by studying sitting, arm and trunk postures of 78 matched pairs of male and female workers in diverse labour markets. Karlqvist et al. (2003) show that there are differences between male and female samples with regard to metabolic level, muscle endurance and fitness. This may also be attributed to the physical build of males compared to females. A counter argument is proposed by Coury et al. (2002) in a study of a repetitive industrial work tasks involving 103 workers (84 female and 19 male) where no differences in MSD symptoms between males and females were found. They state that the replacement of female workers by male workers is worthless. However, non-significant results could be due to the big disparity in gender distribution in this study.

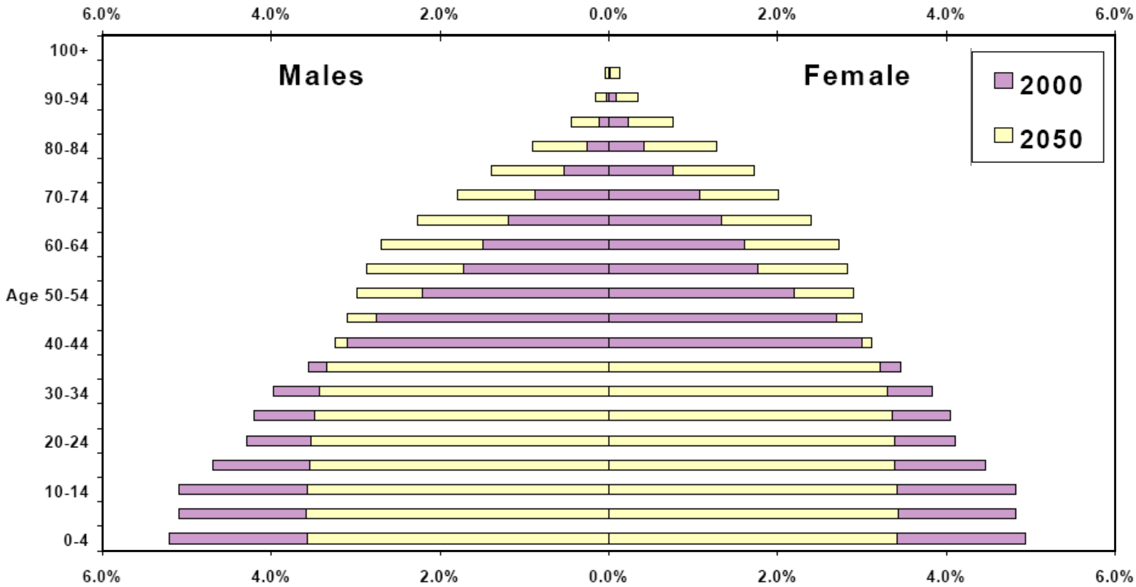


Figure 2.4. World population pyramids in 2000 and 2050 (ILO, 2001)

- Build (physique): Physical build is a contributing factor for MSDs. Males and females have different physical capabilities and limitations due to physique (Karlqvist et al., 2003). As a result, the ability to withstand or adapt to physical factors plays a role in the prevalence of MSDs. In addition, weaker individuals seem to be more vulnerable to MSDs since they lack the ability to adapt (Kumar, 2001). This is one of the reasons to promote physical exercise as a strategy to increase an individual's ability to cope with physical exposure levels (Hermans and de Beek, 2000; Fenety and Walker, 2002).

2.4.3. Psychosocial factors

Devereux (2005) quotes that psychosocial risk factors refer to the subjective perceptions of workers regarding aspects of the organisation of work. Work organisation and psychosocial risk factors have been categorised in terms of demands, control, support, relationships, role and change (Feuerstein et al., 2004). It is also reported that, a high exposure to a combination of physical and psychosocial work risk factors produces a greater risk of developing new episodes of self reported MSDs (Kilbom, 1994a; Health Council of the Netherlands, 2000; Hanse, 2002; Jensen et al., 2002; Devereux, 2005).

Many psychosocial risk factors have been identified and include low work content (Lacey et al., 2007), work style (Feuerstein et al., 2004), low social support (Kindenberg et al., 2006), negative affectivity (Johnston et al., 2008), household work, leisure time (Fredriksson et al., 1999; Hildebrandt et al., 2000), a high perceived work load (Fredriksson et al., 1999; Health Council of the Netherlands, 2000; Jensen et al., 2002), time pressure (Health Council of the Netherlands, 2000), management support (Hanse, 2002), low job control (Lacey et al., 2007), perceived stress (Health Council of the Netherlands, 2000), high psychological job demands (Fredriksson et al., 1999; Kindenberg et al., 2006), occupational status (Jensen et al., 2002) and socioeconomic group (Lacey et al., 2007). There are other potential psychosocial factors also that have been associated with MSDs such as dietary habits (Xu et al., 2008) and smoking habit (Palmer et al., 2003; Johnston et al., 2008).

Psychological stress, which has been given prominence in research related to work-related MSDs could be considered as a psychosocial factor (Aptel and Cnockaert, 2002). Supporting this, Theorell et al. (2002) suggest from a clinical study that tissues are at risk during periods of stress. A study on stress-induced muscle effort as a cause of MSDs also reveals association between stress and MSDs (Rietveld et al., 2007). In addition, a study by Vroman and MacRae (2001) lends credence to the physiological underpinning of stress, where stress and life events were shown to be positively associated with the presence of upper extremity disorders and measures of intensity, duration and frequency of pain.

2.5. Reducing the risk of MSDs

Various attempts have been made to reduce the prevalence of MSDs among the working population (Ruotsalainen et al., 2006; Escorpizo and Moore, 2007; Denis et al., 2008; Rivilis et al., 2008). A plethora of intervention programmes (e.g. Morken et al., 2002; Helland et al., 2008), standards (e.g. BSI, 1999; 2007a; 2007b) and guidelines (e.g. HSE, 2003; NIOSH, 2007; Choobineh et al., 2007, Hoozemans, 2008) have been developed to eliminate workplace risk factors (Cohen et al., 1997; Westgaard, 2000; Rivilis et al., 2006). As expected, there are numerous reported studies of successful MSD reduction programmes in the literature. Some of these, which are relevant to the research, are discussed in Section 2.4.1. Although unsuccessful ergonomics programmes are seldom published (Hignett et al., 2005; Denis et al., 2008), they can also be considered important for the development of this area.

2.5.1. Intervention programmes

Intervention programmes are defined as a targeted set of actions carried out in a workplace within a defined period of time, whose purpose is to implement changes directly related to work or otherwise (e.g. stress management course, physiotherapy program and exercise break), in order to prevent or curb MSDs (Denis et al., 2008). Integrated preventive strategies that address all risk factors (i.e. physical, patho-physiological and psychosocial) are likely to be most effective in reducing work-related MSDs (Cole et al., 2002; Devereux et al., 2002; Burton et al., 2009). Intervention programmes are widely conducted at present with a view to reducing work-related MSDs (Cole et al., 2002; Denis et al., 2008). According to Cohen et al. (1997), ergonomics intervention programmes typically undergo a sequence of steps (Table 2.3).

Another intervention process, the ‘work compatibility improvement framework’ is proposed by Genaidy et al. (2007; 2008). This four-step process consists of: (1) measurement of demand/energiser profile of work characteristics; (2) measurement of work compatibility; (3) generation of improvement action (solutions without specifying how changes are made) and (4) development of customised interventions (implementable solutions subject to enterprise constraints).

These processes essentially cover preliminary analysis, a diagnostic stage and solution development as suggested in a review of intervention programmes by Denis et al. (2008). Their review also reveals that interventions consist of the application of standards, adaptation of standards and development of new designs. They report three types of interventions based on the participation of experts and users: participation of only experts, only users and both experts and users. Many authors, for example, Kuorinka et al. (1994) and Burton et al. (2009) agree that the involvement of users is important in bringing about change to reduce work-related MSDs, and it is commonly known as participatory ergonomics.

Table 2.3. Sequence of steps that ergonomics programmes undergo (Cohen et al., 1997)

Step	Description
Step 1	Looking for signs of work-related musculoskeletal problems
Step 2	Setting the stage for action
Step 3	Building in-house expertise
Step 4	Gathering and examining evidence of work-related MSDs
Step 5	Developing controls
Step 6	Healthcare management
Step 7	Proactive ergonomics

2.5.2. Participatory ergonomics

Wilson and Haines (1997) define participatory ergonomics as:

> *Involvement of people in planning and controlling a significant amount of their own work activities, with sufficient knowledge and power to influence both processes and outcomes in order to achieve desirable goals.*

Participatory ergonomics involves users in different stages of the design process to achieve project objectives (Wilson, 1995; Hignett et al., 2005). Worker involvement is systematically obtained in these programmes using different user oriented methods and tools (Hignett et al., 2005). These are important elements in participatory approaches that support practitioners in collaboratively identifying user requirements (Haslegrave and Holmes, 1994; Broberg, 2007b). Wilson and Haines (1997) identified improved design ideas and solutions, smoother implementation and a number of systemic outcomes of value to both organizations and individuals as reasons to promote participatory ergonomics approaches.

Participatory approaches have been used in many ergonomics related projects for product and process development (Kuorinka and Patry, 1995; Vink et al., 1995; Hignett et al., 2005; Cullen, 2007), and participatory methods are increasingly utilized in improving the ergonomics aspects of work and workplaces (Kogi, 2006). There is ample evidence in literature to recommend the use of participatory design approaches (Kuorinka and Patry, 1995; Rivilis et al., 2006; Vink and van Eijk, 2007). Several approaches that facilitate the participatory ergonomics process are discussed.

The participatory ergonomics framework (PEF)

Haines et al. (2002) described a framework for participatory ergonomics (Table 2.4).

Table 2.4. The participatory ergonomics framework (PEF) (Haines et al., 2002)

Dimensions	Description
Permanence	Ongoing, temporary
Involvement	Full direct participation, direct representative participation, delegated participation
Level of influence	Group of organizations, entire organization, department, work group/team
Decision making	Group delegation, group consultation, individual consultation
Mix of participants	Operators, line management, senior management, internal specialist/technical staff, union, external advisor, supplier/ purchaser, cross industry organization
Requirement to participate	Compulsory, voluntary
Focus	Physical design/specification of equipment/workplaces/work tasks, design of job teams or work organization, formulation of policies or strategies
Remit	Problems identification, solution development, implementation of change, set-up structure process, monitor/oversee process
Role of ergonomics specialist	Initiates and guides process, acts as expert, trains participants, available for consultation, not involved

The authors conclude that this framework can be applied to setting up and supporting participatory ergonomics initiatives and programmes. The framework also makes a contribution to a better fundamental understanding of what is involved in participatory processes for ergonomics change. According to the authors, this framework only provides generic advice and guidance by providing structure to the field of participatory ergonomics. After validation through case studies and peer evaluation, PEF has been suggested as an initial basis to produce practical guidance on participatory ergonomics programmes. ‘Focus’ and ‘remit’ are important aspects of the PEF that focus on design, but as mentioned, specific detailed guidance on any of these aspects is not given, and this limits the use of this framework. Participatory ergonomics processes address these aspects of design separately, and give significance to generation of improved design ideas and solutions and smoother implementation to facilitate the design process.

The 9-step participatory ergonomics process

Vink and van Eijk (2007) citing from Bobjer and Jansson (1997) report that participatory design involves an 11-step approach involving a rigorous product development process with repeated testing and modification phases. Vink et al. (2008) build on the 11 step process for participatory ergonomics and list the stakeholder involvement in 9 different participatory steps (Table 2.5).

Table 2.5. The 9-step participatory process

Step	Description
Introduction	Planning the process, informing participants, defining the main focus, defining the effects to be measured
Analysis	Studying experienced problems and determining impacts on productivity and health
Idea generation	Selecting main problems, making an overview of existing solutions, brainstorming improvements, designing concepts
Idea selection	Discussing the feasibility of ideas and concepts and selecting improvements with the work force and management
Prototyping	Detailing design of one or more solutions, manufacturing of parts or working prototype
Testing	Testing the selected improvement
Adjusting	Adjusting the design based on testing
Implementation	Training the participants, buying materials, setting up new organisation/workstations
Evaluation	Measuring experienced and objective effects, adjusting improvements, evaluating the process

Both the 11-step and 9-step participatory ergonomics processes essentially cover the design lifecycle for a product, and continuous improvement is emphasised in both processes. However, the 9-step process provides a more succinct elaboration of the user evaluation and conceptual design stages. A review by Denis et al. (2008) reveals that improvements to equipment, facilities, procedures and training can contribute towards workplace improvement. Hence, these processes may be extended from design of products to the design of equipment, facilities, procedures and training to cover all facets of work environments and work tasks to help reduce work-related MSDs.

Other participatory ergonomics processes

There are also other participatory ergonomics processes discussed in literature with different levels of detail and scope. The participatory approach discussed by Sundin et al. (2004) for product development has four different phases: (1) formation of a work group; (2) analysis of existing product; (3) analyses of prototypes of the new product and (4) computer visualisation. The work group involved in the process mainly included designers, engineers and experts in ergonomics. One criticism of this participatory process is that workers are involved only during prototype evaluation.

Further, Kogi (2006) reports on several participatory ergonomics programmes developed based on a checklist approach to provide quick-help to practitioners. These include, work improvement in small enterprises- WISE (ILO, 2004; Kawakami and Kogi, 2005); risk reduction in small and medium-sized enterprises and construction sites (Hiba, 1998; Ito et al., 2006); work improvement in neighbourhood development- WIND (Khai and Kawakami, 2002); work improvement for home workers- WISH (Kawakami et al., 2006) and participation oriented safety improvement by trade union initiative- POSITIVE (Kawakami et al., 2004). The core participatory steps in these approaches are: learn from good practices (set visible goals), change group (self help action), immediate implementation (locally practicable changes) and follow-up activities for encouraging continuous improvement. A generalised three-stage participatory approach of initiative building, planning and implementation and follow-up based on his review of such participatory programmes has been suggested by Kogi (2008). These participatory processes have been developed using checklists and suggestions for improvement with diagrams, and in the view of the author, are based on the ‘ergonomics checkpoints: Practical and easy-to-implement solutions for improving safety, health and working conditions’ (ILO and IEA, 1996). Although these participatory processes give ample guidance to the user, they are not flexible enough to be applied in a variety of work tasks and environments. Moreover, the aspect of innovation is neglected. However, these approaches also give prominence to continuous improvement.

Pehkonen et al. (2009) discuss a participatory process using a two-phase approach, pre-implementation and implementation. This process is described as a method of empowering the workers to implement changes in the workplace by having workshops at different stages of the design process facilitated by an ergonomist. This process also identifies the importance of aspects of user evaluation and design under the pre-implementation phase. However, recommended tools and techniques for the process are not provided, which therefore limits its use.

There are also reported instances of participatory approaches developed by industry (Wikström and Hägg, 1999; Butler, 2003; Hägg, 2003; Moreau, 2003; Munck-Ulfsfält et al., 2003; Smyth, 2003). For example, the programme developed at Peugeot (Moreau, 2003) involves collection of medical data (general disorders and MSD diagnoses), analysis of methods employed by technicians using a 37-item questionnaire and analysis of repetitive tasks in detail to help proactively manage MSD risks. Many participatory processes developed by industry are confidential and do not reveal in detail the tools developed. As a result, there is no review by external independent reviewers (Hägg, 2003) and no circulation in the public domain.

A limitation of participatory processes (apart from those that use checklists) is that they only provide a broad level approach, which is often vague [e.g. processes by Sundin et al. (2004) and Pehkonen et al. (2009)]. They do not provide enough detail on the procedures and guidance, which is vital for a participatory approach. It may be due to the diversity of the problems encountered in industry and the tools and techniques available that could be used in participatory ergonomics processes. Criteria for the selection of problems and tools and techniques need to be specified if procedures and guidance are to be provided with participatory processes. However, it may make the participatory approaches complicated. One way of avoiding this is to limit the scope of the participatory approaches, that is, to make the processes problem or application specific. It will limit the scope of the processes, but would increase the potential to provide detailed guidance and supplementary tools and techniques to accompany them. Another way to avoid this is to provide generic tools to practitioners so that they could customise according to their needs. These may be the reasons for the industries to develop their own participatory approaches that use specific tools and techniques to suit the environments unique to them.

2.6. Improving participatory approaches

The benefits of using participatory design approaches is undisputed, but there is little evidence of emerging supportive theory, and relatively little generic advice or guidance (Haines et al., 2002). As discussed above in Section 2.4, participatory processes emphasise aspects of design, but do not provide detailed guidance for practitioners that involve in the improvement of work tasks and workplaces. It limits the applicability of the processes in the industrial setting. Thus, the literature was reviewed with respect to ways of improving participatory design.

2.6.1. Stakeholder participation

The collective participation of stakeholders in the design process is required (Colombini and Occhipinti, 2006; Vink et al., 2008; Burton et al., 2009). For example, Burton et al. (2009) state in a review on management of work-related upper limb disorders that, emergent evidence indicates positive outcomes in engaging all the stakeholders that include employers and workers acting in a coordinated fashion. Unfortunately, it is not always apparent (Vink et al., 2008) and likely to create a communication gap in the design process (Dul et al., 2003). Researchers such as Slappendel (1994), Shinnar et al. (2004), Broberg (2007a) and Marshall et al. (2010) further suggest that there is a drawback in the design process where a mismatch exists between the user requirements and what is ultimately produced.

On one side, there are the users that directly interact with work tasks and the work environments in production (to produce goods) or service (to provide services) systems. On the other, there are practitioners of design such as engineers, architects and designers that take part in designing equipment, facilities, work procedures and training programmes to improve work tasks and work environments with the view of reducing work-related MSDs. There are also other practitioners such as managers, ergonomists, industrial engineers and health and safety personnel that influence design decisions. Users (workers) that are exposed to workplace factors of MSD risk and all these practitioners could be considered as stakeholders of the design process in relation to the design of equipment, facilities, work procedures and training programmes to reduce work-related MSDs.

In the communication process, user requirements may not be clearly conveyed to these practitioners involved in design so that they could incorporate appropriate design solutions to prevent work-related MSDs. Engelbrektsson (2002) discovered by conducting focus group sessions with different participant groups that, inexperienced product users provide less information about products than the users with product experience. Therefore, there may also be a possibility that the user requirements pertinent to the reduction of work-related MSDs may be incomprehensible even to the user that directly interacts with the systems (Darses and Wolff, 2006). In other words, the users' perspective is not fully understood by the design practitioners, and vice versa. For example, in the case of using computer based representation of products in developing usable products, Gyi et al. (2010) conclude from a study with older participants that these methods enable communication of product properties to the designers, but cautions that users do not fully understand the detailed designs when these methods are used. The issue may be similar with respect to the user ability to communicate requirements with respect to equipment, facilities, procedures and training to reduce the risk of MSDs. The result is, essential user requirements to reduce MSDs are not being reflected and prioritised in design.

A mechanism to bridge the gap between the users, design and other practitioners in the design process may help reduce work-related MSDs (Bruseberg and McDonagh-Philp, 2002; Dul et al., 2003). This fact is embodied in a case study by Cullen (2007) involving a high hazard industry (i.e. gas processing facility). In this study, the author has integrated human factors to introduce liaison across engineering design and operations planning to develop an operational facility that reduces risk. Integration had been carried out according to the framework illustrated in Figure 2.5 where standard techniques such as checklists and stakeholder consultations were used. The process had involved both operations personnel and system designers. It had helped to avoid the formation of a gap between the system designers and the end users. The study demonstrates the advantages of early human factors integrated approaches as compared to later assurance approaches, and concludes that without human factors integration, systems designers and end users may not have an adequate understanding of each other's requirements. Liaison across engineering design and operations personnel in this study resulted in workable solutions with reduced risk of operability.

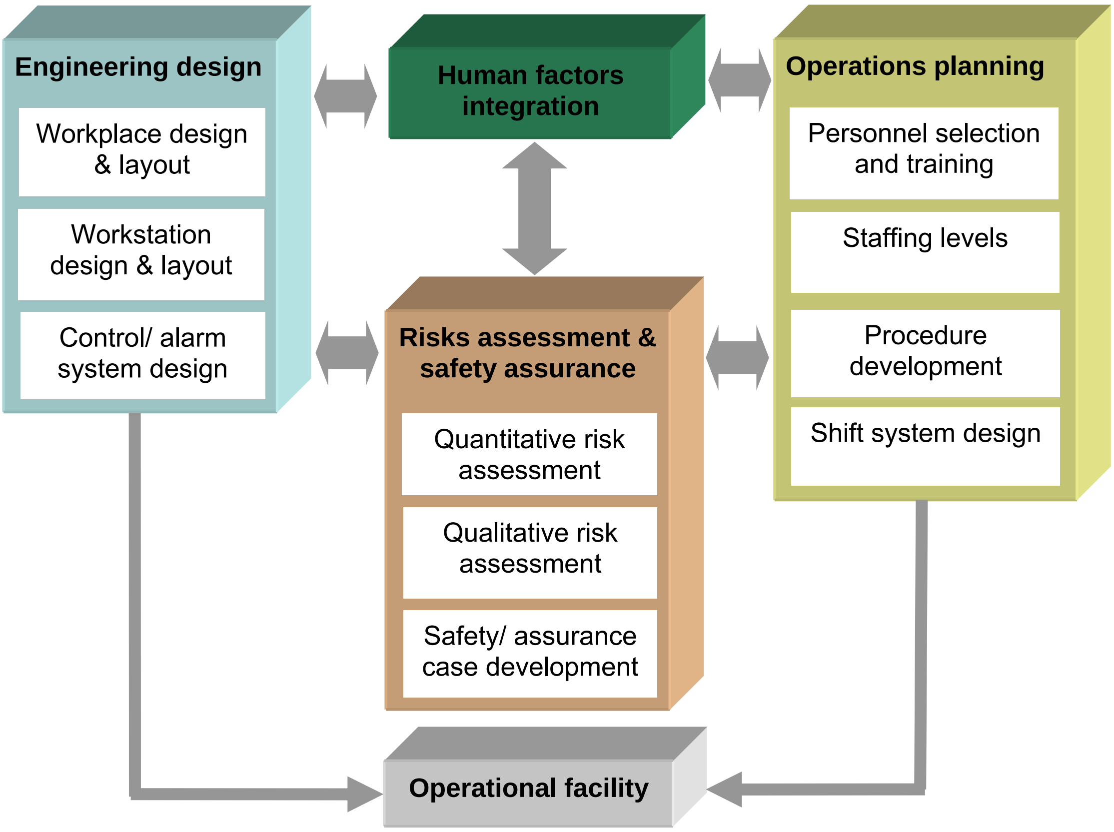


Figure 2.5. Typical project major workstreams with human factors integration [adapted from Cullen (2007)]

Thus, effective communication among the stakeholders is a key factor to ensure that design practitioners understand the requirements of the users (workers) to prevent work-related MSDs. Collaboration among the stakeholders is desirable and it has produced results. For example, a study by Graves (1992) describes how co-operation between workers, medical, engineering and ergonomics disciplines resulted in the improvement of an assembly line redesign that ultimately helped reduce the risk of upper limb disorders. In addition, involving the users in the design process will result in making the designs more effective and help reduce MSDs among the users (Wilson, 1994; Boy, 2006). Furthermore, the changes are more likely to be accepted by the users (Wilson and Morris, 2004). In order to facilitate communication, a systems ergonomic approach based on a participatory model that engages key stakeholders is advocated (Dul et al., 2003; Buckle, 2005).

Interestingly, recent research shows that ergonomists have identified the importance of involving the users in intervention programmes (Vieira and Kumar, 2007; Entzel et al., 2007). For example, Vieira and Kumar (2007) assessed 64 welders and 44 computer numeric control (CNC) machine operators in the steel industry in order to identify risks for work-related low back disorders. They conclude that the information from the workers is useful in redesigning the jobs, illustrating how workers can significantly contribute to this process. In addition, Entzel et al. (2007) report the findings from a meeting with a cohort of 43 stakeholders involved in the reduction of work-related MSDs in masonry trade that included 12 tradespeople to suggest changes to the masonry construction practices and conclude that they intentionally brought in tradespeople to influence the decisions on the ways to reduce work-related MSDs.

Moreover, researchers (Whysall, 2006; Whysall et al., 2007) have gone to the extent of finding ways of determining the stage of change of workers and managers prior to their involvement in intervention programmes to reduce work-related MSDs. The questionnaires suggested by them are used to categorise the process of change into five stages: pre-contemplation (resistance to recognising or modifying problem behaviour); contemplation (recognising problems and thinking about changing, but are not ready to act); preparation (intending to change in the next 30 days and/or have made specific plans to do so); action (having made changes no more than 6 months ago) and maintenance (having made changes more than 6 months ago and working to consolidate gains made). The argument of the authors is that, after identifying the stage of change, it becomes possible for the practitioners to develop bespoke intervention programmes to better suit the workers and managers, and would potentially result in establishing lasting solutions.

However, methods to facilitate such intervention programmes are a necessity (Broberg, 2007b). According to a case study conducted by Bruseberg and McDonagh-Philp (2002), when designers had an opportunity to understand more about the user tasks and the user environment, they valued that information. However, some of the designers in this case were sceptical about obtaining information directly from the users themselves. This may have been due to the fact that there is no accepted method to derive the needs of users effectively.

Communication among all stakeholders in the design process is an important aspect to consider. Researchers have become interested in communication between disciplines in general, because good communication is vital for good interdisciplinary and participatory relationships (Mayfield and Hill, 2007). Communication means not only purely written and spoken language, but also visual communication, genre, modes of communication and settings for communication (Mayfield and Hill, 2007). The synergy that could be achieved through communication is modelled for health promotion and design professionals in Table 2.6, where a shared aim to facilitate positive change in behaviour and experience is emphasised. However, it is acknowledged that it is challenging to develop collaborative design methods to suit different people and teams. For example, Wang et al. (2002) report findings from a review of literature and projects on state of the art and future trends of collaborative conceptual design. They cite that conceptual design starts with high-level description of requirements and proceeds with high-level description of a solution where the basic solution path is laid down. According to them, different stakeholders with conflicting requirements such as customers, designers and engineers take part in the process, and the decisions of one often affects the others making the conceptual design process complex. They also state that no automated tools are found that facilitates the initial phase of the conceptual design process due to the complex nature of the design process.

Table 2.6. Model of synergy between health promotion and design as summarised by Mayfield and Hill (2007)

Model	Health promotion	Design
Holistic	Addresses all aspects of clients lives as factors affecting health	Recognises the impact of individual and context as affecting interactions with artefacts
Inter-disciplinarity	Works in collaboration with and knowledge from related disciplines and delivery mechanisms	Works in collaboration with, and knowledge from all disciplines relevant to the project and its delivery
Client/user centred	Focus on health of targeted group rather than agents of delivery/management	Design specifically for the needs of the end user, not necessarily intermediaries
Inclusive	Consideration of needs of clients from all backgrounds and social situations	Design for access and usability by all potential users
Social models	Works to enable rather than problematise the individual	Works to alter the environment rather than the individual
Broker/ facilitator role	Coordinates provision from key stakeholders around client's need	Collates and addresses needs of key stakeholders through design outcome

Haines et al. (2002) emphasise difficulties that are inherent in participatory ergonomics programmes such as the perceived time and cost involved; the effort required to turn interventions into continuous improvement programmes; the need to motivate participants and understanding how to embrace those represented, but not active in the process. Thus, methods that reduce the time involvement of participants, help continuous improvement and eliminate other factors that may lead to non-participation may help a participatory design process.

2.6.2. Use of participatory tools and techniques

Participatory approaches have many advantages to successful product and process development, but adhering strictly to a procedure during execution may prove a barrier to success (Kuorinka and Patry, 1995). Any procedure can be kept as a guide, but providing flexibility in the process may be considered as vital for a participatory design approach.

In order to make participatory design effective, appropriate methods have to be used. There is a strong need to adapt these methods to different work settings (Kogi, 2006). A wide range of participatory tools and techniques can be used within a participatory framework. It is usual to see a progression with an expert practitioner such as an ergonomist facilitating the process from problem identification and definition through to the testing of solutions. The steps may include problem analysis using both quantitative and qualitative methods to facilitate the overall process and data collection in the real world setting (Hignett at al., 2005). However, often, methods seem to be used in isolation and an integrated approach that combines the different phases of the participatory process may be useful for practitioners.

Cole et al. (2006) concludes that "*considerable opportunities exist to expand the range of integrative interventions, particularly at the organisational and system level, and incorporate a combination of knowledge transfer and exchange with intervention evaluation*" to help reduce work-related MSDs. A high prevalence of MSDs is a symptom of system failure and should be addressed to improve overall quality and productivity (Buckle, 2005). A systems approach could be used to help minimise workplace risk factors (Karwowski, 2005) and therefore, it is plausible that the prevalence of MSDs could also be reduced. Another challenge faced by researchers that develop approaches for participatory design is validation. As mentioned by Haines et al. (2002), multi-factorial approaches that use different methods are difficult to validate, and participatory frameworks require validation before becoming a basis for guidance.

In summary, research suggests that more interventions are required and the methods currently being used can be improved to reduce work-related MSDs as supported by Ruotsalainen et al. (2006). Aspects of design may be a priority in reducing work-related MSDs (Buckle, 2005; Karwowski, 2005). Amell and Kumar (2001) also, strongly advocate design as a prevention strategy for work-related MSDs. As Kinkaid (1999) states, "*Working to improve ergonomics in the workplace is also working to enable maximum performance*". So a reduction in the vulnerability towards developing work-related MSDs may in turn save labour hours and reduce related costs. In order to achieve this, an approach that would facilitate participation of the stakeholders that could take part in the design process may prove to be an area for further research.

2.7. Design as a work-related MSD reduction strategy

Dempsey et al. (2000) have analysed 134 definitions of human factors/ergonomics from different sources and found that the term 'designing' appeared in these definitions 114 times. Other terms that have a frequency of occurrence of more than 100 are human (180) and systems (104). This signifies the importance given in ergonomics towards designing of systems for humans. A categorisation of the terms that occur more frequently in human factors/ergonomics definitions is shown in Table 2.7. It shows that the goals are achieved by providing engineering and design solutions to systems, machines and equipment etc., which are in different environments.

Table 2.7. Terms assigned to a simple category structure describing human factors/ ergonomics (Dempsey et al., 2000).

Who	What	How	When/where	Goal
Human	System	Engineering	Environment	Safety
People	Machine	Designing	Work	Comfort
Users	Equipment	Applying	Life	Efficiency
Person	Product	Studying		
	Technology	Optimising		

Dempsey et al. (2000) further suggest a short description for human factors/ ergonomics: "*A multidisciplinary endeavour that involves the design and engineering of systems for human use"*. Thus, design could be regarded as being at the core of ergonomics. Furthermore, Amell and Kumar (2001) discuss extensively that design is a prevention strategy for work-related MSDs and conclude that, unfortunately, there are only a few design interventions universally applicable due to the fact that work tasks and the contexts in which the work tasks are carried out are different from one intervention to the other. They also believe that cross-job task transfer of design principles may help by making it possible for past solutions to be used in future job tasks to abate work-related MSDs, and this could be considered as extremely important for continuous development of work tasks and workplaces and knowledge sharing.

2.7.1. The design process

An understanding of the phases of the design lifecycle is important in reducing work-related MSDs. This section describes the design lifecycle and specific design models and methods that may be used in participatory design to potentially reduce the workplace risk factors for MSDs.

When a product is designed and ultimately delivered to be manufactured, it follows a series of interrelated phases. All these phases from problem identification through to the generation of information to be handed over for manufacturing as a whole are known as the design lifecycle (Eder, 2001). Individual phases of the design process are arranged according to different rationales to provide structure to the design lifecycle. These are known as design models (Cross 1994; Sivaloganathan et al., 1995). Although these are defined focusing on product design, the models could be considered in the design of facilities, procedures and training as well.

Design models can be divided into descriptive and prescriptive models (Cross, 1994; Sivaloganathan et al., 1995). A descriptive model is a general guideline that simply describes the sequence of activities that take place in a design process. Prescriptive models are more elaborate than the descriptive design models and show patterns among the activities. Study of the prescriptive models may provide an insight into the phases of design (Sivaloganathan et al., 1995) and to identify interrelations between different phases of the design lifecycle. Table 2.8 summarises the discussion of design models described in the review of Cross (1994).

Table 2.8. Popular design models and their features (Cross, 1994)

Model	Salient features
Four stage descriptive model	Input: Design requirements

Model	Salient features
	Output: Conceptual design Based on a four stage flow diagram Iterations during the conceptual design stage
French's descriptive model	Input: Need Output: Working drawings Based on an eight stage flow diagram Analysis of the needs to establish the needs Iterations during the conceptual design stage
Archer's prescriptive model	Input: Data Output: working drawings and information to the manufacturer Signifies the interactions among different stages of the design process Attention to sub problems Prototyping and validation studies
Pahl and Beitz's prescriptive model	Input: Information about the requirements Output: Detail design, production, technical and economic feasibility Based on a seven stage flow diagram Clarification of tasks Establishment of functional structures, searching for suitable solution principles and combining them into concept variants. Determine the layout and forms and develop a technical product or system
VDI prescriptive model	Input: Task Output: Product documentation Based on a nine stage flow diagram Model is considered as problem focused rather than solution focused

Model	Salient features
March's prescriptive model	Input: design requirements Output: detailed design Concept: designer needs to explore and develop both the solution and the problem simultaneously Utilisation of engineering principles Induce alternative concepts to provide a solution Examine the problem in various situations throughout the design process Interrelationships among different stages

Archer's model (Figure 2.6) is a prescriptive model. Unlike the others, it has distinct data collection and analysis phases: These are main elements of participatory approaches.

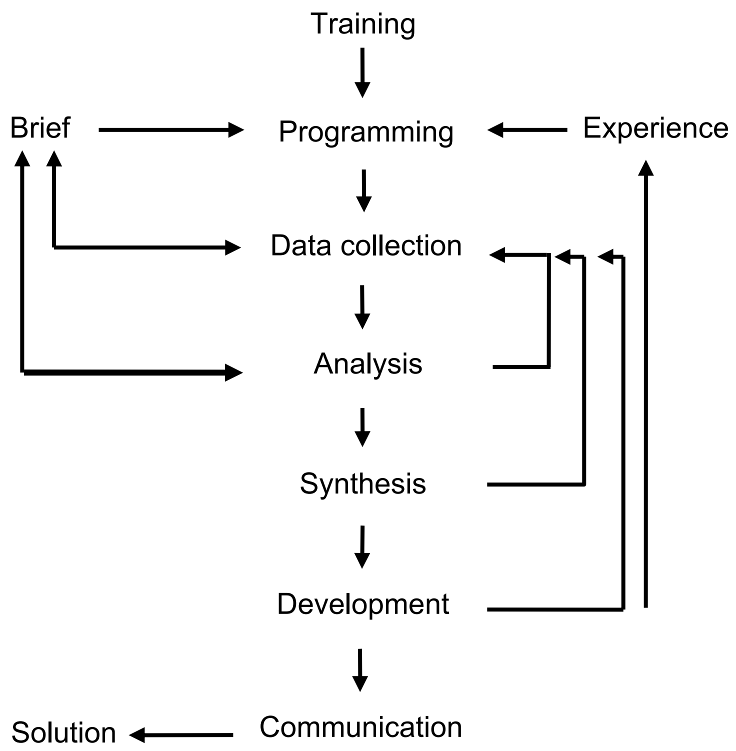


Figure 2.6. Archer's model of the design process [adapted from Cross (1994)]

Archer's model being relatively simple is likely to provide an adequate structure for a design approach in the industrial setting. In essence, it distinguishes three phases in the design process; namely, analytical phase (that involves observation and inductive reasoning), creative phase (that requires involvement, subjective judgement and deductive reasoning) and executive phase (that involves working drawings and information to the manufacturer). Interestingly, this model gives prominence to the creative and communication phases, which are vital in developing innovative solutions to the problems in the industry. Furthermore, this model closely associates with the generic participatory processes discussed earlier.

However, design models alone would not provide solutions and facilitate design requirements to minimise work-related MSDs in industry. Various stages of the model have to be supported by appropriate methods to help formalise and systematise activities within the design process and bring design thinking into charts and diagrams (Sivaloganathan et al., 1995).

2.8. Design methods to help reduce work-related MSDs

Methods that are used to assist in the design process can broadly be defined as processes developed by human beings to improve, resolve and design human artefacts (Cheng, 2003). There are two broad groups of design methods, namely, creative and rational. Yet at times, design methods are rejected by designers thinking that they are too systematic hindering creativity even though they may prevent overlooking essentials in the design problem (Eder, 2000). Design methods can be different tools, techniques or procedures and are also known as formal methods (Marshall, 1998). Formal methods can be explained within the framework of linear and concurrent engineering.

2.8.1. Linear engineering and concurrent engineering

Linear engineering, also known as serial or sequential engineering involves sequential consideration of the product lifecycle, where stakeholders of the design process work independently of each other, use conventional engineering tools and the customers and suppliers are not involved in the process (National Academy of Sciences, 2002). As stated by Marshall (1998), sequential engineering encompasses the entire product lifecycle, but the element of concurrency is not present giving rise to low interaction among the different stages of design and manufacturing.

As the National Academy of Sciences (2002) cites, concurrent engineering is defined as "*a systematic approach to the integrated, simultaneous design of products and their related processes, including manufacture and support*". This approach is intended to encourage developers, from the outset, to consider all elements of the product lifecycle from conception through disposal, including quality, cost, schedule and user requirements. Concurrent engineering has more to do with both the designing and manufacturing aspects of the product lifecycle (Albin and Crefeld, 1994; Balamuralikrishna et al., 2000; Domizio and Gaudenzi, 2008) and strives to represent all stakeholders in the design process (National Academy of Sciences, 2002).

Although both linear engineering and concurrent engineering can be used to integrate the design process, there are clear differences between the two approaches (Yazdani and Holmes, 1999). In linear engineering, integration is predominantly present only between two adjacent steps in the process, whereas in concurrent engineering, integration is promoted along every phase of the design cycle (Jones, 2007). In addition, linear engineering does not give prominence to the involvement of users in the design process. Therefore, the concept of concurrent engineering is more suitable for an integrated design approach to help bridge the communication gap between users and the practitioners of design and potentially reduce workplace risk factors for developing MSDs. Hence, investigation of methods used in concurrent engineering is worthwhile.

Concurrent engineering methods such as quality function deployment (QFD) (Akao, 1990) and axiomatic design (Suh, 1990) could potentially be used to effectively communicate design information and enhance collaboration among the stakeholders in the design process. In addition, there have been other methods presented such as the design function deployment (Sivaloganathan et al., 1995) and trans-disciplinary design (Gumus et al., 2007) based on QFD, axiomatic design and other methods to facilitate the design process. Further study of these methods is essential in order to determine the feasibility of these methods in the context of this research.

2.8.2. Quality function deployment (QFD)

QFD was initially developed in Japan in the late 1960s and early 1970s (Terninko, 1997; Chan and Wu, 2002; Akao and Mazur, 2003). It was introduced to the USA in the 1980s (Chan and Wu, 2002) and to Europe in 1983 (Akao and Mazur, 2003). Subsequently, this promising methodology spread to almost all parts of the world (Lu and Kuei, 1995; Akao and Mazur, 2003; Anderson, 2006).

Akao (1990), the founder of QFD (Day, 1993; Terninko, 1997; Marshal, 1998; QFD Institute, 2009) defines it as a method for converting the ‘customer demands’ into ‘quality characteristics’ and developing a design quality for the finished product. It does this by systematically considering the relationships between the customer demands and the quality characteristics. It starts with the quality of each functional component and relates them to the quality of each part and process. The overall quality of the product will be formed through this network of relationships. A comprehensive definition for QFD is also given by Day (1993): "QFD is a process - a methodology - for planning products and services. It starts with the voice of the customer; *this is the input*. The customers' wants and needs become the *drivers* for the development of requirements for the new or revised product or service". The QFD process requires a number of inputs and decisions that are best done through teamwork. Terninko (1997) further defines QFD as a detailed system for translating the needs and wishes of the consumer into design requirements for products or services. Detailed analysis can be extended to the design of systems, parts, processes and control mechanisms, which results in greater profits and increased market share.

In essence, in the design process, the subjective desires of the customer are mapped onto the language of the engineer. QFD focuses on delivering value by understanding customer requirements and deploying these desires throughout the development process (Wörz and Zaworski, 2008). According to Verma et al. (1998) and Eder (2001), QFD essentially covers the following areas, and it is therefore a tool suitable for concurrent engineering:

- Identification of customer needs and preferences
- Establishment of a relationship between customer needs and engineering design characteristics
- Identification of interrelationships between the engineering design characteristics
- Evaluation of competing products
- Linking engineering design characteristics and component characteristics
- Linking component characteristics with process operations
- Linking process operations and control parameters
- Implementation
- Continuous improvement

The house of quality matrix for the QFD process was first developed in Japan in 1977 (Akao, 1990). Figure 2.7 shows a typical house of quality used in QFD. It represents the systematic nature in which design of products or systems can be carried out while keeping track of activities that have already been carried out (Eder, 2001). The house of quality matrix could also be used to analyse and visualise design information (Kurniawan et al., 2004). This makes it useful for a participatory design approach where participants from different backgrounds (e.g. users, managers, ergonomists and design engineers) may take part. As a result, it can be considered as important for the proposed research.

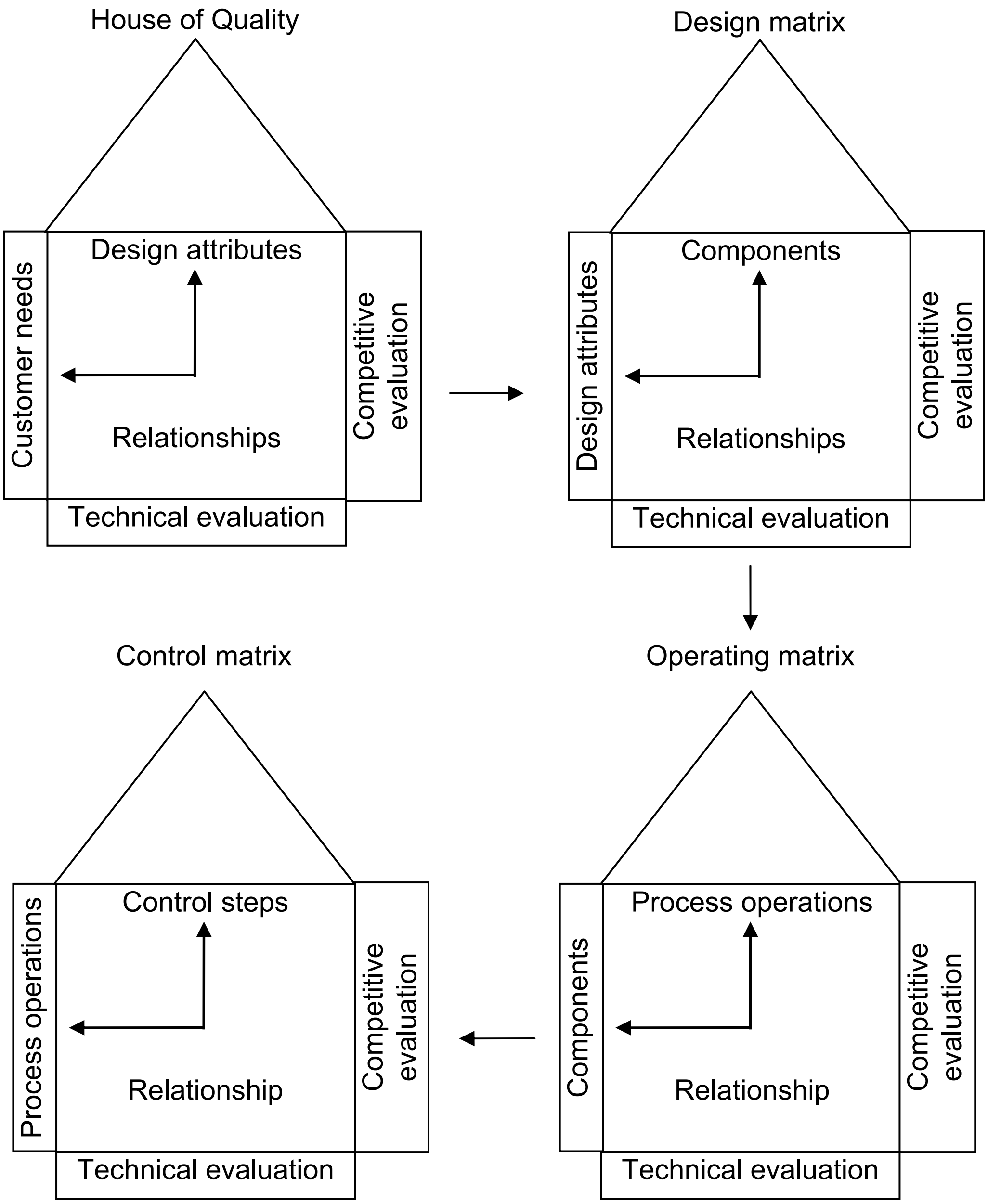


Figure 2.7. The QFD process using house of quality [adapted from Lai et al. (1998)]

2.8.3. Axiomatic design

Axiomatic design was introduced and described by N.P. Suh in the 1970s and considers design as a science, which is governed by axioms and principles. Axiomatic design uses the term 'functional requirements' to represent design requirements and the term 'design parameters' to represent solutions. According to Suh (1990), axiomatic design is a matrix-based design approach to map design parameters to functional requirements. This process flows through the design lifecycle and manufacturing covering the user environment, functional domain, physical domain and process domain. It also ensures that functional requirements are addressed throughout the process by having relevant design parameters similar to the QFD process (Figure 2.8).

Axiomatic design is based on two governing principles known as the independence axiom (i.e. maintain the independence of functional requirements) and the information axiom (i.e. minimise the information content of the design) (Suh, 1990). The intention of introducing these axioms is to achieve the simplest feasible solutions for a given design requirement. Axiomatic design is considered to be a logical and systematic approach (Brown, 2005) to designing new products, and has been successfully used since its inception (Suh, 1990). Different aspects of axiomatic design has also been applied in ergonomics (Helander and Lin, 2002; Kurniawan et al., 2004). Moreover, the ability of axiomatic design to be integrated with other tools and techniques makes it versatile as a design method. For example, Shirwaiker and Okudan (2008) describe the ability of axiomatic design to be used synergistically with the theory of inventive problem solving, also known as TRIZ, which itself is a design method, to achieve efficiency and quality in design.

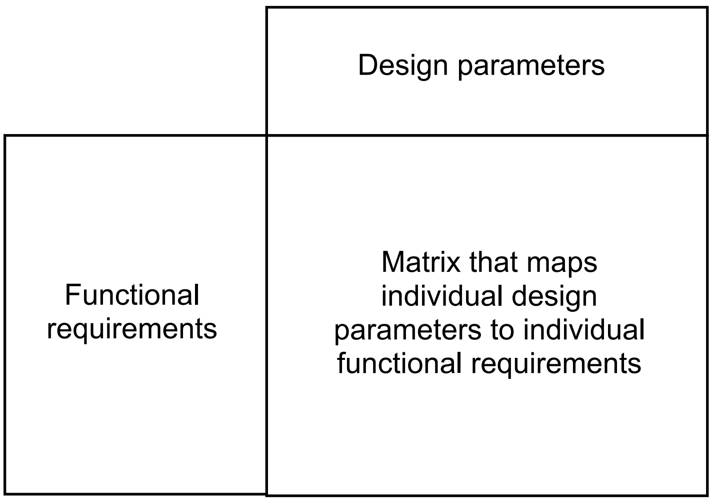


Figure 2.8. A typical axiomatic design matrix

2.8.4. Design function deployment

Design function deployment (DFD) discussed by Sivaloganathan et al. (1995) is based on QFD. It also uses matrices similar to QFD, and closely relates to the QFD process (refer Section 2.7.2). It has been developed to be a software-based system. Modules for graphical user interface, design process control, communication, design management, design tools, product modelling, knowledge base management and database management have been integrated with QFD to facilitate the design process.

2.8.5. Trans-disciplinary design

Trans-disciplinary design (Gumus et al., 2007), a method based on axiomatic design is proposed to encompass the testing domain, which comes after the development of a product as well as the features of the original axiomatic design method. It covers the whole product development lifecycle and helps develop, capture and present both the big picture and a detailed view of product development knowledge. This includes visualising design solutions, functional requirements (requirements for design), relationships between design solutions and functional requirements, and has the ability to trace back to the changes in the design along the product development process. It facilitates product development teams in the design process. Gumus et al. (2007) argue that this process could be used in the development of products, systems, services and organisations in many different disciplines. Basically, this method sticks very closely to axiomatic design, and can be considered an extension to the axiomatic design method.

2.8.6. Product lifecycle management

There have been concurrent design models developed based on distributed product lifecycle modelling (Zhang and Xue, 2001). Product lifecycle management concepts attempt to integrate all phases of design in the design process (Sudarsan et al., 2005; Sharma, 2005) for design information management and easy communication among all stakeholders. These models mostly cater for product development and use advanced architectures and computer technology extensively (Zhang and Xue, 2001; Sharma, 2005; Nahm and Ishikawa, 2006). For example, Zhang and Xue (2001) describe an approach to identify the optimal product realisation process by modelling alternatives using genetic algorithms and particle swarm optimisation, two well known computer based optimisation techniques.

2.8.7. Review of design methods

Cross (1994) and Jones (2007) provide an elaborate account of methods that can be used with design models to facilitate the design process. To support the models, they suggest methods to explore the problems in detail, explore the problem structure, search for ideas, and finally, methods to evaluate the solutions. Wang et al. (2002) describe that, capturing users' intent, problem solving strategies and lifecycle concerns such as manufacturing and reliability are important features of a collaborative design process and emphasise on the initial stage of the design lifecycle. They further mention that an opportunity to develop tools to help in the conceptual design stage is present. This is illustrated in Figure 2.9.

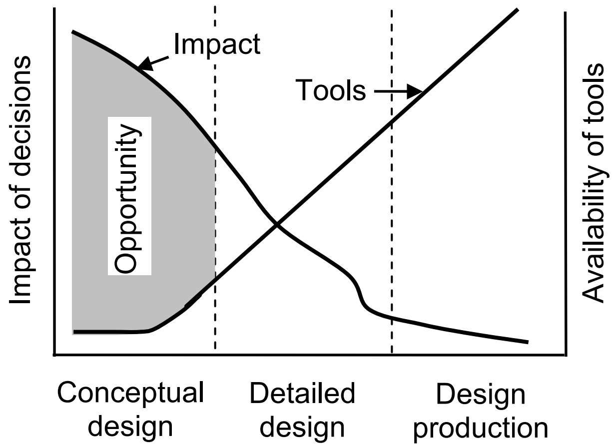


Figure 2.9. Opportunity in early design stage (Wang et al., 2002)

Concurrent design methods encompass all the features in the design process, and the methods described in the previous sections essentially allow a platform to record and audit the design process. In addition, they provide a means of managing design information by helping to integrate the design process. In order to facilitate integration between different phases of the design process and to enhance collaboration among stakeholders of the design process, various other tools and techniques are added to the original method [e.g. design function deployment (Sivaloganathan et al., 1995)].

Although the addition of specific tools seems to increase the utility of the design methods, it limits the flexibility of them. These methods will also show increased complexity with the addition of tools and techniques. For example, Aziz et al. (2005) state that current product lifecycle management implementations are document oriented, have a non-customisable data model and pose inter-enterprise integration difficulties. This makes these methods fit into only a specific type of design (e.g. product design). Furthermore, design methods need to be easy to learn and should not take much time to apply (Brouwer and van der Voort, 2008). The increased complexity of design methods does nothing to reduce either time to learn or time to implement. Furthermore, design tools such as product lifecycle management systems are often proprietary software tools that are expensive. As a result, use of project lifecycle management tools in the industry is justifiable only when the scale of the projects is large. There are instances where open source project lifecycle management implementations are reported (Aziz et al., 2005). Yet, they will need considerable alterations in order to be used by practitioners to reduce work-related MSDs, as they have been developed specifically for product development processes. They will also require knowledge and time to modify according to the needs as well as time to learn and implement.

Preserving the flexibility of design methods to cater for different needs is important. As Wang et al. (2002) conclude from a study on collaborative conceptual design, knowledge-level communication among distributed design modules, integration of various available design tools and bridging the multitude of models that support complex design issues at various stages of the design process are difficult to achieve. They further view using relevant models in each task and communicating the results in a suitable form to stakeholders as a challenge in the conceptual design stage. This may be the reason for the relatively frequent use of QFD and axiomatic design as the basis for design tool development. For example, both design function deployment proposed by Sivaloganathan et al. (1995) and trans-disciplinary design proposed by Gumus et al. (2007) are based on QFD and axiomatic design, respectively.

Both QFD and axiomatic design seem to possess a higher potential (than the other methods) discussed as tools to manage design information. Both can be integrated with other tools and techniques to facilitate the design process. Helander and Lin (2002) cite from a review by Yien and Tseng (1996), that QFD and axiomatic design have been considered as the premier methodologies for evaluation of design quality justifying the above notion. Moreover, like all concurrent design methods, the concept of continuous improvement in total quality management (TQM) is supported by keeping track of the information and information flow throughout the design process. Continuous improvement is important in any collaborative approach to design, whereby design information is preserved and used to continuously develop the product. It seems that, these two design methods have the potential to be developed into a collaborative design tool to reduce work-related MSDs.

Furthermore, Helander and Lin (2002) suggest that design methods should analyse user requirements, map user requirements to the design features and help to choose alternative designs based on consistent quantitative criteria. QFD gives prominence to the analysis of user requirements, and researchers (e.g. Kurniawan et al., 2004) even suggest integrating QFD into axiomatic design to help connect the customers to the process. In contrast, axiomatic design proves better than QFD in choosing alternative designs because it uses design principles and axioms that help choose optimal designs quantitatively. However, since axiomatic design uses a matrix based approach with complicated analysis techniques using mathematical concepts, it may not be feasible in an industrial environment where stakeholders with different capabilities need to communicate to make design decisions. It should be noted that, both these methods have limitations, but QFD seems better suited as a tool to enhance communication to be used by practitioners in industry to help reduce work-related MSDs.

QFD defines attributes of a design according to the user requirements, however, Helander and Lin (2002) state that QFD does not provide guidelines for effective design decisions. Axiomatic design is suggested as a straightforward design method that may be used to improve the performance of QFD by reducing its complexity (Gonçalves-Coelho et al., 2005). This suggests that features of axiomatic design could be used to enhance the performance of QFD.

Interestingly, there have been previous applications of QFD in ergonomics (e.g. Bergquist and Abeysekera, 1996; Marsot, 2005). Marsot (2005) even suggests QFD as a methodological tool to ensure ergonomics criteria in designs. However, there have been no reports in the published literature where QFD has been used to develop tools to enhance communication among stakeholders in participatory design processes. Further discussion of QFD, its application and how it can be adapted to facilitate communication among stakeholders in the design process to reduce work-related MSDs in industry is presented in Section 4.2.

2.9. Summary

MSDs are prevalent in industry around the world. With the aging population, the occurrence of MSDs is likely to increase. Many terms are used synonymously to describe MSDs and have been attributed to myriad of work-related factors. From the review of literature, three broad categories of risk factors for MSDs were identified; namely, physical, psychosocial and patho-physiological. However, further research is needed for comprehensive categorisation.

In order to reduce work-related MSDs, it was identified that workplace risk factors need to be minimised. One way this can be accomplished is through intervention activities such as ergonomics programmes that involve users at different stages of the design process (participatory ergonomics). Researchers suggest different participatory frameworks and processes that could be used in order to assist practitioners to alleviate work-related MSDs in industry. Although participatory processes cover the entire design lifecycle of mainly products, they could be extended to cover all facets of design; namely, equipment, facilities, procedures and training.

The literature suggests collective participation of the stakeholders in the design process in participatory design processes. However, it was apparent that there is a void between the users and practitioners of design creating a mismatch between user requirements and what is ultimately produced to help reduce work-related MSDs. Although there are instances where models for communication have been developed, approaches and tools to facilitate communication among the stakeholders in a participatory approach to design are required.

An understanding of the design process and methods that could be used is needed in order to develop approaches to enhance collaboration among stakeholders. Hence, methods that can be used to enhance communication among the stakeholders in the participatory design process were evaluated. Among those described in literature, quality function deployment (QFD) has potential to facilitate the participatory process. QFD may be used to develop an integrated tool to help design in reducing work-related MSDs. Although QFD has been used in the past in designing ergonomic products, it has never been used as part of a participatory design approach, as a tool that enhances communication among various stakeholders of the design process to reduce work-related MSDs.

3. User requirements study

3.1. Introduction

It was identified through the literature review that work-related MSDs are commonplace and research is still necessary to reduce them. It also showed that participatory approaches to design have been effective in improving working conditions, although practitioners and employees (users) in general are not always involved in all phases of the participatory design process often creating a mismatch between user requirements and what is ultimately designed or produced. It further revealed that user participation in the design process is crucial to aid understanding and to harness ideas for design improvement.

Methodologies and tools for user participation are important elements in participatory design approaches. They support practitioners in collaboratively identifying risks and requirements for design to reduce work-related MSDs. However, it is important to investigate whether users are able to effectively participate in participatory processes. Thus, the aim of the study presented in this chapter is to evaluate user knowledge and ability to identify workplace risks and the subsequent requirements for design in order to reduce the risk factors for developing MSDs (refer Chapter 1: Objective 1). The study consisted of the following sub-objectives:

- To describe the musculoskeletal health of the user groups;
- To obtain perceived workplace risks and user requirements to reduce the risk of work-related musculoskeletal problems;
- To verify the user identified risks and requirements.

In this pursuit, detailed information pertaining to work processes and worker perceptions of workplace risk factors for MSDs have to be gathered. In addition, an understanding of the risks and user requirements for design to prevent work-related MSDs is necessary. A case study strategy was adopted since it enables the researcher to access in-depth information about a particular issue or situation from different sources using multiple methods (Flick, 1998; Creswell, 2007; Saunders et al., 2007). Within this case study strategy, sampling, data collection methods, procedures and analysis are discussed.

3.2. Sampling

Organisations, local to the Loughborough area involved in retail (n= 4), manufacturing (n= 2) and service industries (n= 1) were initially contacted by telephone about the study. Follow-up letters or emails were then sent out to a named contact providing further detail and requesting a time to meet. Preliminary meetings were arranged with the managers of the organisations that were interested to discuss their expected involvement and details of the study, such as possible work tasks, data collection procedures, requirements of the workers and scheduling.

The work task areas were selected in close consultation with the line managers. Denis et al. (2008) describe two classifications of work characteristics. One of the classifications is according to ‘workstation layout’ (stationary workstation and variable environment), the other is according to ‘nature of task’ (cyclic and varied work tasks). From these classifications, four (i.e. ${}^{2}C_{1}$ x ${}^{2}C_{1}$) combinations of ‘workstation layout’ and ‘nature of task’ could be derived. These are: a stationary workstation and cyclic work task, a stationary workstation and varied work task, a variable environment and cyclic work task, and, a variable environment and varied work task. The aim was to purposively select case study areas (work tasks) to include these four work characteristics.

Followed by the meetings with the researcher, the workers selected for the case study areas were initially informed about the study by their line managers. Participation in the study was voluntary and those who decided to participate informed their line managers. Informed consent (Appendix 3.1 and Appendix 3.2) was obtained from all participants and the Loughborough University ethical guidelines (Loughborough University, 2003) for studies involving human participants were observed.

3.3. Data Collection

Initially, the data collection proformas were piloted using colleagues (n= 3) and changes were incorporated according to their suggestions. They were; changing the order of selected questions to maintain the flow of the interview, replacing technical terms with colloquial terms (e.g. musculoskeletal troubles with aches and pains) and highlighting keywords to help follow the proformas. After incorporating the changes suggested by the pilot subjects, the full scale study was undertaken.

Workers from the selected organisations were informally observed for approximately 30 minutes in order to fully understand the work tasks. Then, semi-structured interviews were conducted with each worker to investigate their perceptions of the workplace risk factors for MSDs and their perceived requirements for design to reduce such risks. The interviews were held using an interview guide (Appendix 3.3) and were audio-recorded using an Olympus® VN-2100PC digital voice recorder. A summary of the interview guide is given in Table 3.1. Interviews were all conducted on-site during work time. Probing questions were asked as necessary throughout the interviews to clarify points of interest and to obtain details.

Table 3.1. Summary of the interview guide

Section	Elicited information
Personal information	Age, gender, height, weight and ethnic background.
Job information	Job title, work experience, working hours and work schedule.
Awareness of MSDs	Based on the stage of change questionnaire (Whysall et al., 2007) modified to include an open ended question regarding any changes that have been made in the past by the employers. In addition, the phrase ‘musculoskeletal problems’ was replaced with “aches and pains” so that the workers could more easily understand the question.
User requirements	Perceived user requirements for the different work tasks by encouraging them to reflect on their work.
Musculoskeletal troubles	Based on the Nordic musculoskeletal questionnaire (NMQ) (Kuorinka et al., 1987). This covered 15 body regions to assess period prevalence- 12 month; point prevalence- 7 day, and severity- the effect on normal activities in the last 12 months. Workers were also asked whether they considered their symptoms could be attributed to work, and if so, to provide possible reasons.
Involvement in the task design decisions	Involvement in the task design decisions was assessed using a 9-point Likert scale (1= no impact at all to 9= very high impact).

After the interviews, workers were directly observed performing the work tasks, and note-taking was guided by work element recording checklists (Konz, 1990) (Appendix 3.4) to help verify the user identified risk factors for developing MSDs. In order to help verify the prioritised themes, risk levels for the observed work tasks were determined using a pen-and-paper-based technique since this could be conveniently used in the industrial setting by practitioners (Li and Buckle, 1999a; David, 2005). The selected technique needed to be able to record data mainly from the video recorded work tasks to help verify the user identified risks. Furthermore, the technique should be able to record force and posture-related information unobtrusively and be suited for work situations that involve both static and dynamic tasks with at times with large positional changes. Table 3.2 summarises potential pen-and-paper-based posture recording methods used by practitioners (Li and Buckle, 1999a; Dempsey et al., 2005; David, 2005) to help select a suitable technique for the assessment.

Table 3.2. Popular pen-and-paper-based methods to assess posture related risks

Technique	Features	Validity and reliability
Ovako working posture analysing system- OWAS (Karhu et al., 1977)	Postures coded using hypothetical numbers for back, upper limbs and lower limbs; assessment of whole body posture	Method successfully used in a steel manufacturing company, provides reliable results when sufficient training is provided to the assessor
Rapid upper limb assessment- RULA (McAtamney and Corlett, 1993)	Postures, forces and repetition coded using diagrams and hypothetical numbers; accounts for loads due to static and repetitive muscle work; risk assessment based on upper limb (head, trunk, upper and lower arms, wrist) exposure; assessment of static tasks	Validated using laboratory tests involving computer data entry operators (n= 16) by comparing RULA scores and subjective ratings; higher validity for neck and lower arm; in general acceptable reliability was observed in a sample of 120 practitioners
PATH (Buchholz et al., 1996)	Posture categories based on OVAKO, considers worker activity, tools used, loads handled and grasp type, uses hypothetical coding system to categorise postures; suitable to assess non-repetitive work	Validated using simulated real time analysis for trunk and shoulder postures based on two work tasks, but further validation is required, intra-observer reliability was high for the limbs and low for the neck and trunk; inter-observer reliability was low

Technique	Features	Validity and reliability
Rapid entire body assessment- REBA (Hignett and McAtamney, 2000)	Builds on RULA; postures, forces, coupling and repetition, coded using diagrams and hypothetical numbers; assessment of static, dynamic or tasks with unpredictable working postures; assess risk levels considering the entire body, coupling and gravity assisted upper limb posture	Practitioners (n= 14) assessed 600 tasks and inter-observer agreement was 62%-85% omitting the upper arm. Validity needs to be further assessed with other practitioners
Quick exposure check- QEC (David et al., 2005; 2008)	Assessment based on exposure of the back, shoulder/upper arm, wrist/hand and neck together with vibration, visual demands and subjective responses of workers towards the work task; suitable for static and dynamic task situations	Tested for sensitivity, usability and reliability using simulated and field tasks with the participation of practitioners (n= 206) and found to have high degree of validity and reliability.

According to Table 3.2, OWAS can be used only to assess posture neglecting forces whereas RULA can be used only to assess the upper limb during static task situations. PATH has been developed to assess only non-repetitive tasks. Therefore, it is not possible to use these techniques in all of the combinations of 'workstation layout' and 'nature of task' discussed in Section 3.2. REBA and QEC could both be used to assess both static and dynamic task situations, but in order to use QEC, a certain degree of worker involvement would be required (e.g. to obtain subjective responses to a work task). Therefore, based on the requirement, REBA, which assesses the risk levels for the whole body without any input from the workers, was selected to be used in the study. A guide was used to record the force, posture and repetition information to help determine REBA risk levels (Appendix 3.5).

Task elements were captured on video (using a Panasonic® NV-DS27 video camera) for approximately 10 minutes. The video camera was set-up to capture information from two directions where recording angles were perpendicular to the frontal and sagittal planes of the workers (Grant et al., 1994; Li and Buckle, 1999a; Bao et al., 2007) whenever no physical obstructions such as walls were present. It was directed as much as possible at the origin of the three intersecting planes (i.e. frontal, sagittal and transverse) to record upper and lower body postures simultaneously during work tasks. These angles were maintained as much as possible to ensure repeatability and reproducibility although it is impossible to achieve full control in the field setting. Workers were also asked to talk through the process wherever possible to better understand the process. Typical work tasks were also captured with a digital camera (using a FUJIFILM® FinePix J10 digital camera) to supplement the video footage.

Finally, whole body discomfort (WBD) scales (0= no discomfort to 6= extreme discomfort) based on Corlett (1990) were distributed to workers (Appendix 3.6) just before and after one hour of work: all worker groups in general worked for one hour slots on a task. The original scale given in Corlett (1990) was maintained without change, but the number of body locations was increased to 25 to tally with the 15 body regions included in the NMQ.

Semi-structured interviews were also conducted with line managers (Appendix 3.7) to obtain job information, awareness of MSDs based on the manager stage of change questionnaire (Whysall et al., 2007) and the involvement in the task design decisions using the same 9-point Likert scale (1= no impact at all to 9= very high impact scale).

3.4. Analysis

Work tasks were analysed using hierarchical task analysis-HTA (Annett, 2005) to identify the first level of task elements. Personal and job information were used to obtain characteristics of the worker sample. Important sections of the interviews were identified and were transcribed by playing back in RealPlayer® version 1.0.1. Narratives from the stage of change questionnaire enabled a judgement of readiness to change behaviour to reduce the risk of MSDs arising from work and their knowledge of work-related MSDs (Whysall, 2006). The percentage of workers that responded affirmatively to each item in the stage of change questionnaire was calculated.

User-identified risks and requirements were extracted from the narratives using techniques to identify themes (Ryan and Bernard, 2003). The themes were identified and defined using the constant comparative method (Glaser, 1965; Erlandson et al., 1993; Boeije, 2002), where the themes identified from one recorded interview were compared with the themes identified from the preceding interviews in a continuous manner using features available in Microsoft® Excel (Meyer and Avery, 2009). This was followed by content analysis to count frequency and allocate priority to the identified themes based on frequency ranking.

Prevalence (and severity) data were summarised for the 15 body areas as part of NMQ using Equation 3.1 and the percentages were graphically presented. Chi-square test of independence was performed using contingency tables to assess whether the prevalence for different body regions is independent of the case study area or participant group: null hypothesis being ‘prevalence is statistically independent of the case study area’ (Anderson et al., 1993). Information on task design decisions (TDD) was summarised by calculating average ratings as shown in Equation 3.2. Kruskal-Wallis test was performed using task design decision ratings to assess whether the populations (case study areas or participant groups) were identical or not: the null hypothesis being ‘different populations are statistically identical’ (Anderson et al., 1993). SPSS® version 16.0 was used for the statistical analysis.

$$\% \quad of \quad the \quad sample = \frac{f}{n} \times 100 \qquad \text{(3.1)}$$

Where,

f = number of workers that reported prevalence (or severity) in a body area

n = total number responded to the particular section of the interview guide

$$TDD = \frac{\sum_{i=1}^{9} r_i \times f_i}{n} \qquad \text{(3.2)}$$

Where,

r_i – ratings (where r_i = 1, 2, … , 9 for i = 1, 2, …, 9)

f_i – number of respondents that selected the rating i (i.e. frequency)

n – total number responded to the particular question in the interview guide

Direct observations supported by video recordings, note taking and photographs were used to triangulate, add detail and to obtain a clearer picture of the user identified risks and requirements. Video recordings were played back in Windows® Movie Maker and most common and extreme postures were identified by closely observing the work tasks. These postures were used to evaluate risks for MSDs (Spielholz et al., 2001; Bao et al., 2007) using REBA risk levels (Hignett and McAtamney, 2000). The REBA risk levels were tabulated with respect to task elements and stature (percentile) of the workers.

To document worker WBD, the mean body discomfort ratings were calculated for each body area at the beginning (Equation 3.3) and after one hour of the task (Equation 3.4). These were graphically presented and a Kruskal-Wallis test was performed to assess whether the ratings were statistically identical or not with respect to the three case study areas: the null hypothesis being 'discomfort ratings are statistically identical' (Anderson et al., 1993). Again, SPSS® version 16.0 was used for the statistical analysis.

$$WBD_{Beginning} = \frac{\sum_{i=1}^{n} WBD_{bi}}{n} \qquad \text{...} \quad (3.3)$$

$$WBD_{After\ one\ hour} = \frac{\sum_{i=1}^{n} WBD_{ai}}{n} \qquad \text{...} \quad (3.4)$$

Where,

WBD_{bi} – discomfort rating of the i^{th} worker at the beginning of shift for a body area

WBD_{ai} – discomfort rating of the i^{th} worker after one hour of work for a body area

n – number of workers that completed the scales

Analysis of the data from managers was similar to that of the workers. Details of related procedures adopted in activities such as assessment of risks and user requirements and introducing new technology and work processes were obtained from the narratives. Manager interviews were also used to triangulate the information provided by the workers.

3.5. Results

3.5.1. Participants

Out of the seven organisations that were contacted, one agreed to participate. Three case study areas were selected from this organisation to include a variety of work tasks/characteristics. These were: cleaning using scrubber drier machines (variable environment and cyclic work task); joinery using workbenches (stationary workstation and a varied work task) and plumbing involving varied work tasks (variable environment and a varied work task). All workers (cleaners: n= 10, joiners: n= 6 and plumbers: n= 6) involved in the studied work tasks and their line managers (cleaners': n= 3, joiners': n= 2 and plumbers': n= 1) participated in the research.

3.5.2. Task analysis

Observations were used to understand the elements of the tasks in the three case study areas. In the cleaners' study, task elements were identified for the mains-operated scrubber drier machines as filling with water and additives, lowering the brush, scrubbing open areas, scrubbing corners and edges and emptying the dirty water tanks. For the battery-operated scrubber drier machines, task elements were filling with water and additives, scrubbing open areas, scrubbing corners and edges and emptying the dirty water tanks. In the joiners' study, five distinct task elements were observed. These were placing material on the workbench, measurement and marking, material removal, finishing, and removing the finished job from the workbench. In the plumbers' study, only two broad task elements were observed. They were cutting pipes and preparing fittings, and connecting the pipes and fittings.

3.5.3. Worker demographics

Descriptive data for the sample are summarised in Table 3.3. Only the participants of cleaners' study included both males and females.

Table 3.3. Characteristics of the worker participants (n = 22)

Case study area	Gender (M/F)	Number of participants	Age (years): mean (SD)	Height (cm): mean (SD)	Experience in the job (years): mean (SD)
Cleaners	M	5	46 (15)	174 (6)	1.6 (1.2)
	F	5	42 (13)	159 (7)	4.2 (4.1)
Joiners	M	6	47 (14)	176 (8)	30.2 (13.4)
Plumbers	M	6	47 (15)	170 (8)	30.7 (15.1)

3.5.4. Worker stage of change

Narratives for the worker stage of change revealed that a large proportion of workers were in the 'contemplation' stage (80%, 83% and 50% of cleaners, joiners and plumbers, respectively). This suggests that they had already made changes to their work in the past and intended to make changes if MSD risks were identified. Examples from the worker narratives are quoted.

> *… rotating the work with others instead of giving to one person (assuming there's two of us to do carpet shampooing) and one of them getting it three days a week and one of them gets it none. So they rotate it slightly and may be the aches and pains blah blah blah won't be so bad after three days of work as such.*
>
> Participant 3: Cleaners' study

> *Oh, they are too numerous to mention. It's just trying different methods. I've always done that. I can't just pick one from the air. It's too numerous to mention. Line manager has tried lots of things. We've altered some of the stuff in the machine shop. In fact, I did it with the line manager. The organisation tries to go and make things as safe as possible it can, safest as practical. So there has never been a problem in that. There will always be risk and there will always changes taking place.*
>
> Participant 5: Joiners' study

> *Now I am trying to get a forklift truck for the yard. I think it will benefit all of us. Not just us. We have lorries coming in loaded. Sometimes it has to be stripped down before lifted by people. So I am trying to get one. That would be a big help to everyone.*
>
> Participant 4: Plumbers' study

3.5.5. Risks and requirements

The ability of these workers to identify risks and determine requirements for design was judged using the interview data. Three examples from the case study areas are quoted.

- All workers in the cleaners' study identified the 'need to lift and carry the dirty water tanks to empty' as a risk for the mains operated machine. Participant 5 mentioned:

> *…. a poor thing about them is, they are alright when being filled up, but when it comes to empty them; the water goes into the top canisters. Then you've got a handle, and you have to pick them up and they are heavy.*

They are heavy! So then you are struggling to get them up and to empty. On the other machine I'd probably say it's easier. If the canister was a solid thing where you could have a pipe to empty the dirty water out like in the automatics.

Participant 5: Cleaners' study

- 50% of the joiners identified the 'need for adjustable workbenches for loading, unloading and to fit different types of work and sizes of people as a design requirement. Participant 1 mentioned:

Perhaps when you carry in loads you can lower it down, put it on the bench and then higher it to your required height so that you can work. The height to which you have to lift is that awkward.

Participant 1: Joiners' study

- 83% of the workers in the plumbers study identified the 'need to eliminate having to apply forces while in awkward postures' in order to reduce risk. Participant 6 mentioned:

There are hot equipment in plant rooms. There is not enough room to turn. Some spanners, sometimes you must have to adjust and shorten up because, especially in old buildings, there isn't enough room to turn. As soon as you shorten it down, you reduce your leverage and there is a more chance of pulling and straining.

Participant 6: Plumbers' study

After the user defined risks and requirements for design were identified using the constant comparative method, they were prioritised by the researcher using frequency analysis. Themes identified by different participants were continuously compared with the previously identified themes and assigned a priority value according to the percentage of participants supporting a particular theme. These are listed for the three case study areas in Table 3.4.

Table 3.4. Prioritised user identified risks and requirements (within brackets, % of workers expressing concerns)

Cleaners (n= 10)		Joiners (workbench) (n= 6)	Plumbers (varied work tasks) (n= 6)
Mains-operated machine	**Battery-operated machine**		
Need to lift and carry the dirty water tanks to empty [100]	Manoeuvring is difficult because they are heavy [60]	Need equipment to lift and/or move heavy objects (materials and equipment) [100]	Having to lift and carry objects (tools and equipment and pipes and fittings etc.) [100]
Dirty water tanks are heavy when filled up [60]	Speed control is not sufficient in the battery operated machine [30]	Required to plan work sequences and material flow to ease work [83]	Need to eliminate having to apply forces while in awkward postures [83]
Wire interfering with the work [60]	Suction lines get clogged [30]	Need to eliminate having to apply forces while in awkward postures [67]	Need methods to prevent having to keep kneeling for long durations [83]
No speed control [40]	Water gushes out when emptying the dirty water tanks [20]	Need adjustable workbenches for loading, unloading and to fit different work types and people [50]	Need to involve in architectural/ building design to facilitate plumbing [67]
Suction lines get clogged [30]	Handle is not height adjustable [20]	Reduce impulse loads and vibration [50]	Need to design fittings to ease installation and maintenance [50]
Having to hold the operating lever and the handle continuously [20]	Battery operated machines do not clean as well as the mains operated ones [10]	Need devices to keep tools for easy access while working on the workbench [50]	Need to reduce high gripping forces when using tools [50]

Cleaners (n= 10)		Joiners (workbench) (n= 6)	Plumbers (varied work tasks) (n= 6)
Mains-operated machine	**Battery-operated machine**		
Avoid the wire being getting in contact with water by holding it with the handle [10]	Machines are difficult to empty and wash [10]	Need to be able to change the position of the vice [33]	Knee pads are good, but need to change them frequently [33]
Need to tilt the machine to get the brush down [10]		Need clamping devices to reduce work holding by hand [33]	Tools and equipment need to be made lighter [33]
Having to stoop over the machine all the time when the machine is in operation [10]		Need steps to secure both feet firmly while working [33]	Need methods to facilitate overhead work [33]
Machines are difficult to empty and wash [10]		Work bench need to be wider to accommodate wider work [33]	Need to eliminate having to climb vertical ladders [33]
		Need to make workbenches movable to facilitate cleaning [33]	Working in pairs to ease the workload is required [33]
		Rotate the tasks within a job to prevent continuous exposure to the same loading condition [33]	Need to eliminate heavy pipe work [17]

Cleaners (n= 10)		Joiners (workbench) (n= 6)	Plumbers (varied work tasks) (n= 6)
Mains-operated machine	Battery-operated machine		
			Need to get everything in place before starting the job [17] Prevent/reduce the use of vibrating tools like drills etc. [17]

Plumbers and joiners identified more risks and requirements for design than the cleaners during the interviews. All workers seemed to easily talk about the risks and requirements resulting from loads/forces. For example, all of them identified requirements related to manual handling. Posture related risks and requirements were discussed less by the workers. Duration or frequency of load/force or posture in most cases was linked with risks and requirements they identified.

3.5.6. Prevalence and severity data

Altogether, 80% of the cleaners (n= 10) and 100% of the joiners (n=6) and plumbers (n=6) reported musculoskeletal symptoms in at least one body area. Considering the data from all the workers that took part (n= 22) from all three case study areas combined, majority (55%; n= 12) of the workers reported period prevalence of musculoskeletal troubles in the lower back. The workers also reported musculoskeletal troubles in the neck (45%; n= 10), the knees (45%; n= 10), the wrists (41%; n= 9), the hands (41%; n= 9) and the shoulders (36%; n= 8). Figure 3.1 depicts the prevalence and severity data for the three case study areas. Cleaners (Figure 3.1.a) reported a high period prevalence (40%; n= 4) of musculoskeletal troubles in the shoulders, wrists and lower back. The point prevalence of musculoskeletal troubles in the shoulders and lower back was also high (30%; n= 3). Joiners (Figure 3.1.b) reported a very high period prevalence of musculoskeletal troubles in hands (67%; n= 4) and high prevalence of musculoskeletal troubles in the lower back (50%; n= 3). The severity of musculoskeletal troubles in the lower back (33%; n= 2) was also high. The period prevalence of musculoskeletal troubles in plumbers (Figure 3.1.c) was extremely high for the neck (100%; n= 6), lower back (83%; n= 5) and knees (83%; n= 5). In addition, the wrists (67%; n= 4) showed very high period prevalence. An extremely high point prevalence was also reported in the knees (83%; n= 5).

Tests of independence to compare the three participant groups with respect to different body regions using Chi-square test statistics showed that period prevalence in the neck was significantly different among cleaners, joiners and plumbers ($p= 0.008$ according to both Pearson Chi-square and Fisher's exact test statistics). Observation of observed and expected counts showed that plumbers had more period prevalence in the neck than the cleaners and joiners. The same statistical test showed that the point prevalence in the knees is significantly different with respect to the three participant groups ($p= 0.009$ according to Pearson Chi-square and $p= 0.013$ according to Fisher's exact test statistic). Observation of observed and expected counts revealed that point prevalence in the knees for plumbers is higher than that of cleaners and joiners.

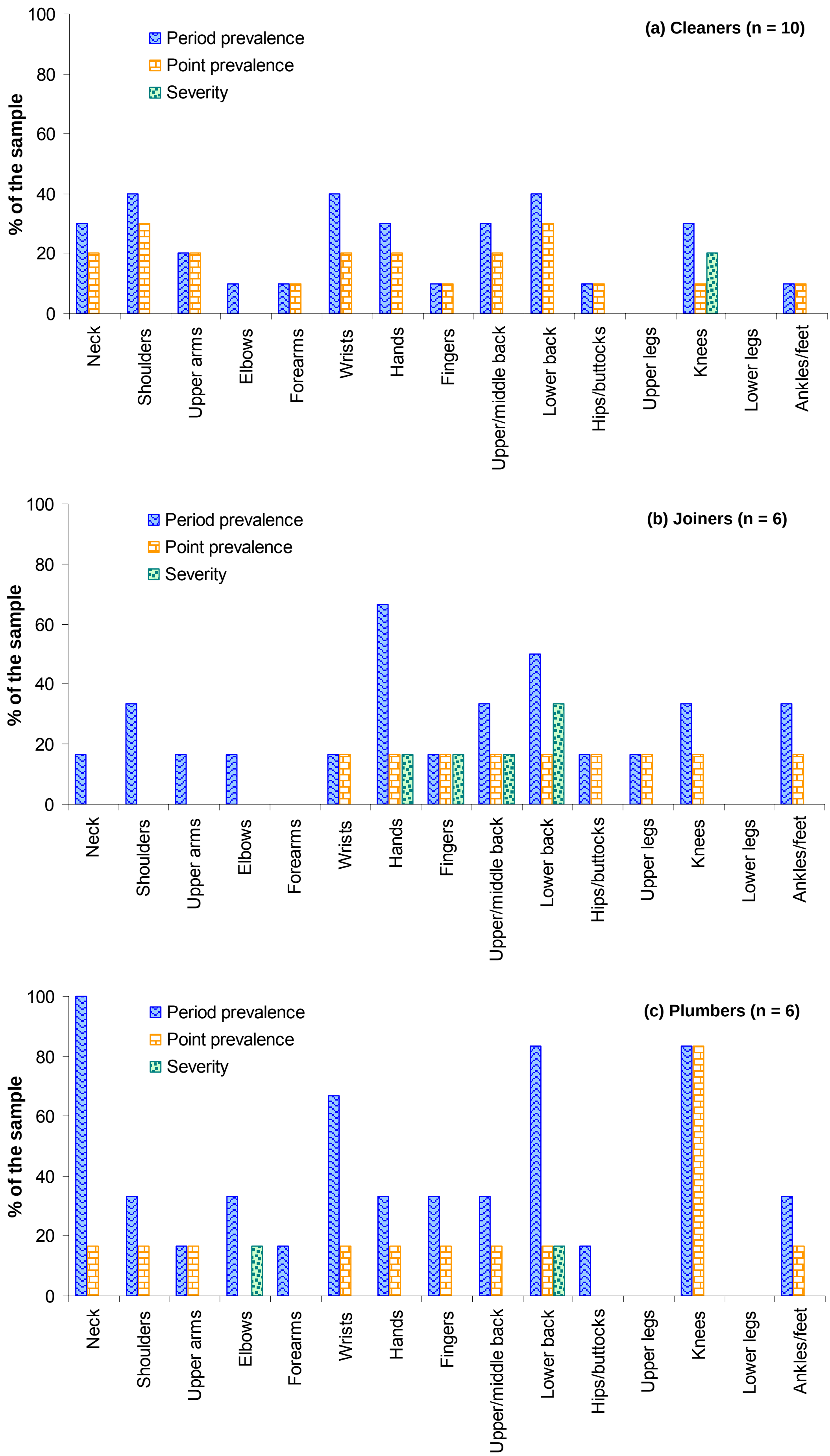


Figure 3.1. NMQ data for (a) cleaners, (b) joiners and (c) plumbers

Workers were also asked to judge whether they thought their musculoskeletal troubles were related to work-related factors. Seven out of the eight cleaners that reported musculoskeletal troubles, judged that they were linked to work-related factors. For example, three of the four cleaners that reported shoulder troubles, associated it with the machine (i.e. bending over the machine, heavy equipment and using it in general) and the other attributed it to age (i.e. age/arthritis). All of the joiners and plumbers viewed that their musculoskeletal troubles were linked to work-related factors. The joiners that expressed hand troubles (67%) viewed impact loads, lifting of weights, gripping, holding things while cold and holding equipment as risk factors. All of the plumbers related their neck troubles to awkward postures, bending and twisting.

3.5.7. Worker task design decisions

Workers rated their involvement in task design decisions using the 9-point Likert scale (1= no impact at all to 9= very high impact). Cleaners generally rated their involvement in the task design decisions lower (mean= 2: SD 1.4) compared to the joiners and plumbers (mean= 4: SD 2.0 and 5: SD 1.0, respectively). The Kruskal-Wallis test revealed that the ratings for the involvement in task design decisions were not identical among the three case study samples (p= 0.003). Examination of mean ranks indicates the low participation of cleaners (mean rank= 6.55) in task design decisions compared to the participation of joiners (mean rank= 14.25) and plumbers (mean rank= 17.00). No correlations were found between the years of experience of the workers and their involvement in the task design decisions.

When asked who gets involved in task design decisions, cleaners in general reported that it was the managers. However, five of the cleaners also mentioned that the managers obtain their opinion about equipment and processes. All of the joiners reported that they convey what they require to the managers and they get a chance to suggest improvements or equipment that they need. All of the plumbers also believed that their managers listened to their opinion in task design decisions.

3.5.8. Direct observations

The observations were used as a means of triangulating the interview data, in particular, the risks identified by the workers and the requirements for design that they suggested to reduce MSDs. Examples are shown in Figure 3.2. Some of the tasks were not identified by the workers as carrying a risk of MSDs even though the observations revealed that the task elements potentially pose a high MSD risk. Examples are given in Figure 3.3.

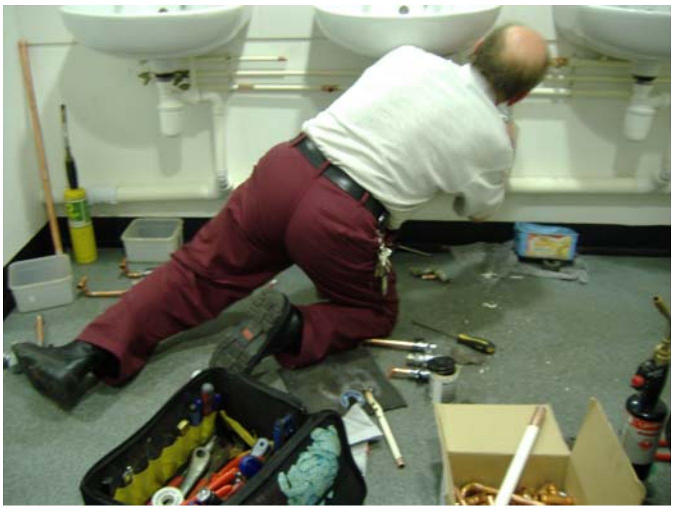
a

Shows a cleaner 'emptying a dirty water tank of a mains-operated scrubber drier machine'. Here, the worker was clearly having difficulty in emptying the dirty water container. The task was made worse due to the lack of space near the drain. The capacity of the container was 15 litres with an estimated weight of 15 kg.

b

Reveals the 'manual handling effort required by the joiners to handle the work'. It was also observed the weight of the job increasing with the progress of the job due to the addition of pieces of material.

c



Illustrates a task carried out by a plumber, which reveals the 'difficulty experienced by the workers during work accessing constrained locations'. The worker is trying to exert a force to connect a pipe while being unstable on one knee.

Figure 3.2. Snapshots of work situations in (a) cleaners', (b) joiners' and (c) plumbers' studies where workers were able to identify risks

a

Shows a cleaner lowering the brush of a mains-operated scrubber drier machine. The worker has an awkward posture and is clearly having difficulty in 'holding the tilted machine while lowering the brush'. The task element becomes worse when the machine is filled with water because it adds 30 kg to the weight of the machine.

b

Reveals a joiner carrying out a finishing task. The worker 'does not use any method of clamping to secure the job on the workbench', resulting in having to stretch to carryout the task element.

c

Illustrates a task carried out by a plumber, which reveals the difficulty experienced by the workers because of the 'inability to get everything in place before starting the job'. The worker has to keep on checking whether the assembly fits the piping arrangement properly, while making adjustments.

Figure 3.3. Snapshots of work situations in (a) cleaners', (b) joiners' and (c) plumbers' studies where workers were less able to identify risks

3.5.9. REBA risk levels

REBA risk levels were calculated using task elements identified from the task analysis for all workers observed during the time that the studies were conducted (refer Section 3.5.2). Figure 3.4 illustrates this process for one of the task elements. Thus, REBA risk levels for three of the cleaners (Table 3.5) and joiners (Table 3.6), and four of the plumbers (Table 3.7) were calculated. According to the REBA assessment criteria, for the cleaners, action is necessary immediately for both the 7^{th} percentile female and 90^{th} percentile male for 'lowering the brush' on the mains-operated machine to reduce the risk of MSDs. For the joiners, the REBA assessment criteria indicated that action is necessary, especially in 'material removal', 'finishing' and 'removing the finished job' from the workbench in order to reduce the risk of MSDs. REBA scores also suggest that action is necessary immediately for plumbers for both task elements, 'cutting the pipes and preparing the fittings' and 'connecting the pipes and fittings'.

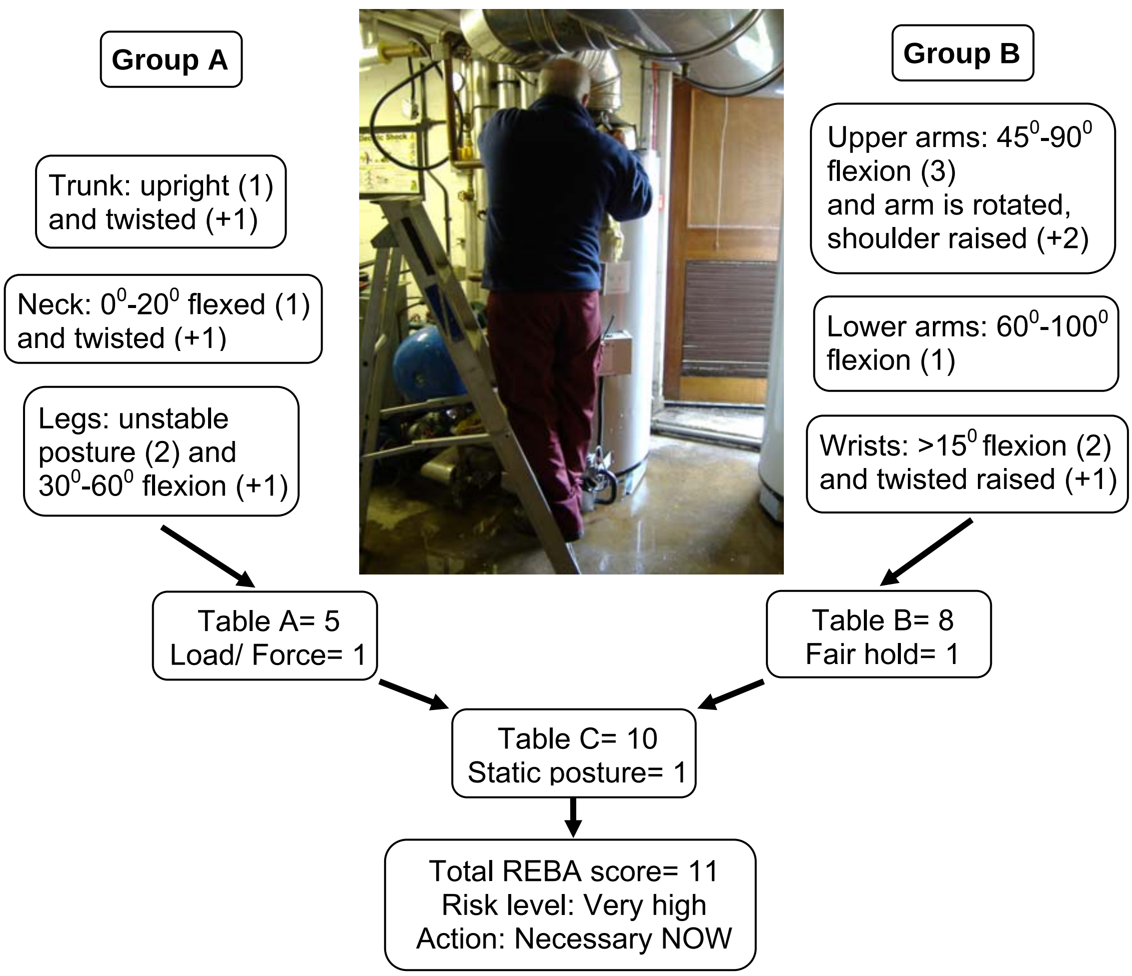


Figure 3.4. Calculation of REBA risk level for the 72^{nd} percentile plumber for the task element 'connecting the pipes and fittings'

Table 3.5. REBA risk levels for the cleaners (with REBA action levels)

Task element	Mains-operated machine		Battery-operated machine
	Risk level for a 7th percentile female	Risk level for a 90th percentile male	Risk level for a 18th percentile male
Filling with water and additives	Low [May be necessary]	Medium [Necessary]	Negligible [None necessary]
Lowering the brush	Very high [Necessary NOW]	Very high [Necessary NOW]	Not applicable
Scrubbing open areas	Medium [Necessary]	Medium [Necessary]	Negligible [None necessary]
Scrubbing corners and edges	Medium [Necessary]	High [Necessary soon]	Medium [Necessary]
Emptying the dirty water tanks	High [Necessary soon]	High [Necessary soon]	High [Necessary soon]

Table 3.6. REBA risk levels for the joiners (with REBA action levels)

Task element	Risk level for a 24th percentile male	Risk level for a 28th percentile male	Risk level for a 98th percentile male
Placing material on the workbench	Medium [Necessary]		
Measurement and marking	Medium [Necessary]		
Material removal	Medium – High [Necessary – Necessary soon]		
Finishing		Medium [Necessary]	High [Necessary soon]
Removing the finished job from the workbench	High [Necessary soon]		

Table 3.7. REBA risk levels for the plumbers (with REBA action levels)

Task element	Risk level for a 1st percentile male	Risk level for a 56th percentile male	Risk level for a 24th percentile male	Risk level for a 72nd percentile male
Cutting pipes and preparing fittings	Medium [Necessary]	Very high [Necessary NOW]		
Connecting the pipes and fittings	Very high [Necessary NOW]	Very high [Necessary NOW]	High [Necessary soon]	Very high [Necessary NOW]

3.5.10. Whole body discomfort

Six of the cleaners and all the joiners and plumbers completed WBD scales. The mean discomfort ratings calculated for all 25 body locations (initial/baseline and after one hour of work) using data from all workers that completed discomfort scales are depicted in Figure 3.5 for the cleaners (Figure 3.5.a), joiners (Figure 3.5.b) and plumbers (Figure 3.5.c). Before starting work, three of the cleaners indicated discomfort in the ankles and feet (mean rating= 1.67: SD 0.58). Three of the plumbers reported initial discomfort in the lower back (mean rating= 1: SD 0.00). Three of the plumbers indicated initial discomfort in the right knee (mean rating= 2: SD 1.73). Four plumbers also reported initial discomfort in only the left knee (mean rating= 1.75: SD 1.50).

After one hour of work, discomfort was particularly a problem in the hands, fingers, upper/middle and lower back, and ankles/feet for cleaners according to the ratings of the cleaners. All of them indicated discomfort in the right hand (mean rating= 2.17: SD 0.98) while five indicated discomfort in the left hand (mean rating= 2.20: SD 0.84). Three indicated discomfort in the fingers (mean rating= 2.00: SD 1.73). Discomfort in the upper/middle back (mean rating= 2.33: SD 0.58) was indicated by three of the cleaners and five indicated discomfort in the lower back (mean rating= 1.40: SD 0.89). Five of the cleaners also indicated discomfort in the ankles/feet (mean rating= 2.00: SD 0.71). Discomfort in joiners is mainly in the upper body regions. After one hour of work, discomfort was particularly a problem in the wrists and right hand and lower back for joiners. Four of them indicated discomfort in the right wrist (mean rating= 1.75: SD 1.50) and three indicated discomfort in the left wrist (mean rating= 2.00: SD 1.73). Discomfort in the right hand was indicated by four of the joiners (mean rating= 2.00: SD 0.82) and discomfort in the lower back was indicated by five (mean rating= 1.80: SD

0.84). After one hour of work, discomfort was particularly a problem in the neck, right wrist and hand, lower back and knees for plumbers according to the mean ratings of the plumbers. Five of them indicated discomfort in the neck (mean rating= 1.60: SD 0.89). Four indicated discomfort in the left elbow (mean rating= 1.25: SD 0.50). Three indicated discomfort in the right wrist (mean rating= 2.00: SD 1.00). Discomfort in the right hand was indicated by three of the plumbers (mean rating= 2.00: SD 1.00) and discomfort in the lower back was indicated by five (mean rating= 2.40: SD 1.14). Five of the plumbers indicated discomfort in the right knee (mean rating= 2.80: SD 1.30) while the number of plumbers that indicated discomfort in the left knee was five (mean rating= 3.00: SD 0.58). In addition, four plumbers indicated discomfort in the ankles/ feet (mean rating= 1.25: SD 0.50). Kruskal-Wallis test results for the body areas that do not reveal identical discomfort between worker groups (i.e. against the hypothesis) are shown in Table 3.8.

Table 3.8. Kruskal-Wallis test results for whole body discomfort

Body area	Mean rank (cleaners; joiners; plumbers)	P value
Left knee (Initial)	8.67; 7.00; 12.83	0.047
Right ankle/foot (Initial)	12.50; 8.00; 8.00	0.034
Left ankle/foot (Initial)	12.50; 8.00; 8.00	0.034
Left elbow (after one hour)	8.42; 7.00; 13.08	0.031
Right knee (after one hour)	7.83; 6.50; 14.17	0.007
Left knee (after one hour)	7.75; 6.50; 14.25	0.006
Right ankle/foot (after one hour)	13.33; 5.58; 9.58	0.028
Left ankle/foot (after one hour)	13.33; 5.58; 9.58	0.028

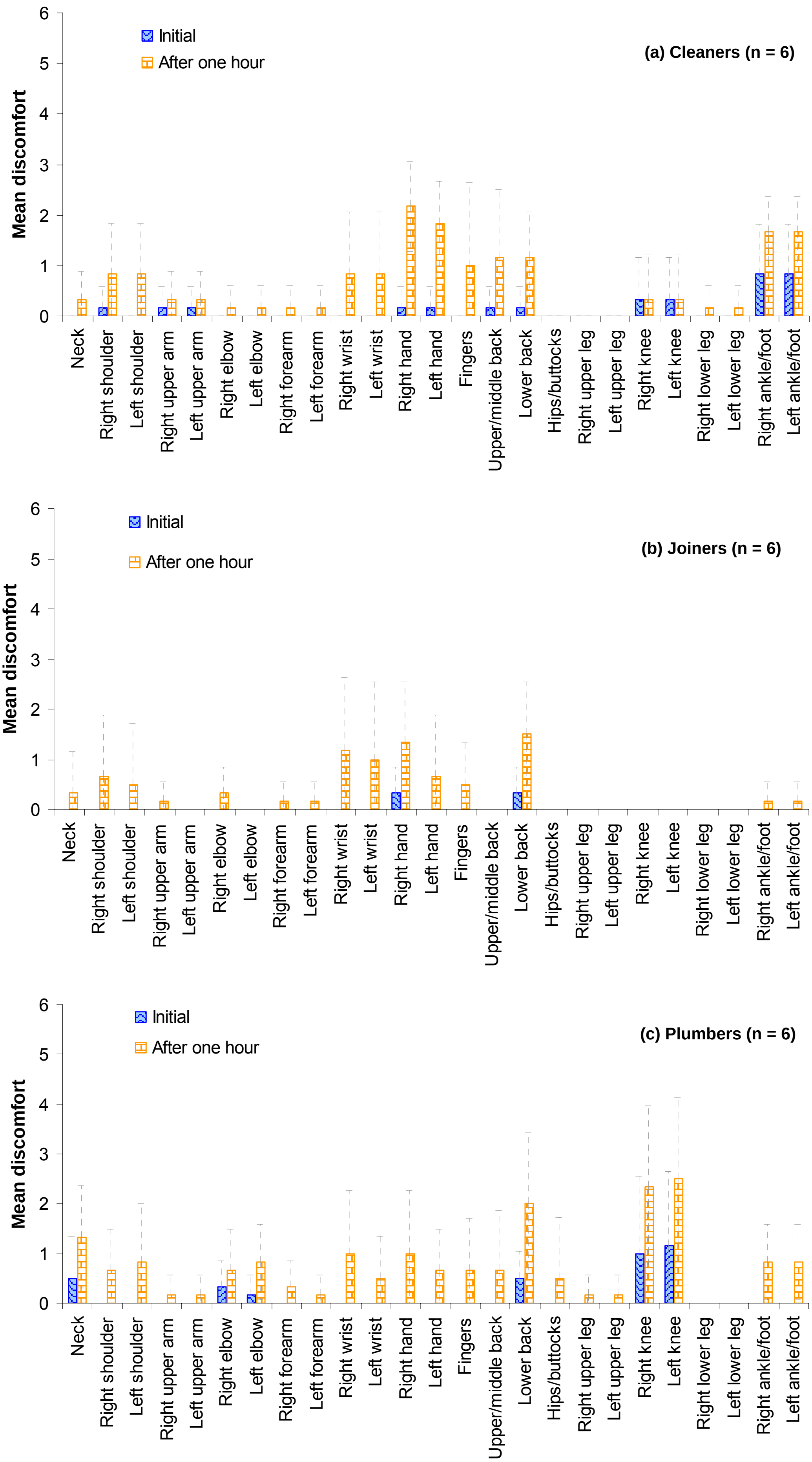


Figure 3.5. Mean discomfort ratings (and SD) for (a) cleaners, (b) joiners and (c) plumbers

3.5.11. Manager interviews

The reported work experience of the line managers is shown in Table 3.9.

Table 3.9. Characteristics of the line manager participants (n = 6)

Case study area	Number of participants	Relevant work experience (years): mean (SD)
Cleaners’	3	7.8 (4.9)
Joiners’	2	8.5 (2.1)
Plumbers’	1	33

All line managers reported that they had taken steps to reduce the risks to workers and had plans to introduce more efficient methods to reduce the burden on the workers. For example, implementation of risk assessment and manual handling procedures and purchasing equipment to reduce risk of musculoskeletal problems:

> *We change everything each year. We're always looking at what we are doing. When I first started here 12 years ago, there wasn't any machine in the building and everything was done with the mop and the bucket. So you got people carrying those heavy mop buckets, the yellow ones everywhere and eventually we started bringing in machines when markets developed, we've improved with the market. One of the first machines was of the size of this desk. We struggled to push it around. Yes, it made the job easier. You weren't mopping all the floors. Yes, we've come a long way.*
>
> Line manager 2: Cleaners’ study

> *We would look at the job, someone will assess the job. Then, someone will do a risk assessment of the job. That would give us an idea of what equipment we need. If we have the equipment, we'll use it. If not, we'd look at purchasing something specific for it. There is a standard risk assessment form we are doing. We look at the task, how the job is going to be done, who is involved and from that we look at the risks, and we look at the way of reducing the risks. Then, it would tell us how it would be handled.*
>
> Line manager 1: Joiners’ study

Introduced weighing scale to weigh tools, equipment etc. and trolleys and small tool bags instead of big tool bags to reduce manual handling. A lot of the equipment that we work with is heavier than the allowed limit. That is why we provided a gantry to aid lifting and a hydraulic lifter for lifting manhole lids.

Line manager 1: Plumbers' study

According to the stage of change assessment (Whysall et al., 2007), these managers were judged to be in the maintenance stage and were working to consolidate changes made to behaviour. Manager involvement in task design decisions was rated as high impact, with a mean rating of 8, 8.5 and 9 respectively for cleaners, joiners and plumbers. These managers did not necessarily check whether the machines complied with the ergonomics guidelines, and relied on supplier information to obtain specifications and checked for compliance by browsing technical specifications:

We are always looking at getting better machines year in year out. See what is available in market. If the machine is not known we ask for a demo. We base the decision on the catalogue information and actually what the salesman has to say, and also what it actually feel from trying it out during the demonstration.

Line manager 2: Cleaners' study

I am aware about ergonomics guidelines and standards. A lot of things that come in have been tested. So we rely on the representatives that come and we can look at it in the internet as well.

Line manager 2: Joiners' study

We get information from the web, manufacturers, and suppliers. The plumbers follow the instructions given in the manuals.

Line manager 1: Plumbers' study

All of the managers had direct experience of the studied work tasks and reported using their experience in the selection of equipment and processes. They also revealed that they encouraged feedback from the workers on the equipment and processes and were actively trying to reduce the effort required to carry out their job:

Myself and Line manager 2 and the staff get involved because we always get the staff to try out or trial what's being brought in and they give feedback on what they think of the machines. In the end, they are the ones who are going to using them. So their input is very important to us.

Line manager 1: Cleaners' study

All the members of the team get involved. Even the workers by talking about things. The workers come up with ideas, easy way or a better tool or something like that, how to do it, and what equipment to use. If there is any restriction, it would be financial. It depends on how expensive it is.

Line manager 1: Joiners' study

I get the input of supervisors and workers as they have the knowledge about the new tools and equipment. We discuss it as a group here. Fitters (plumbers) decide on the site on the method, but it doesn't mean it is the best method, because it may be the method the fitters (plumbers) know.

Line manager 1: Plumbers' study

3.6. Discussion

The user requirements study was conducted to evaluate the user knowledge and ability to identify workplace risks and the subsequent requirements for design in order to reduce the risk factors for developing MSDs. This discussion initially examines the findings of the study with related literature. Then, results of different sections of the study are compared. Finally, the limitations of the study are discussed.

Period prevalence data in the plumbers was very high for the neck (100%), wrists (67%), lower back (83%) and knees (83%). No studies were found that specifically reported the period prevalence of MSDs of plumbers. However, Rose (2007) cites from national statistics that plumbers have more than double the risk of work-related injuries compared to an average of all assessed professions. Albers et al. (2005) also cite from several studies that pipe workers report work-related MSDs. They state that, workers in the plumbing and heating, ventilation and air conditioning (HVAC) sectors experience serious overexertion at rates exceeding the national average for all industries and all construction workers. The joiners predominantly reported musculoskeletal troubles in the hands (67%) and lower back (50%). Although no literature was found specific to joinery, reports on studies of carpenters suggest MSD problems in the neck, shoulders and back (Albers et al., 1997). Patterns of period prevalence in construction workers (that include both joiners and plumbers) have been identified where they report a high period prevalence of neck-shoulders (37%), low back (72%) and knees (52%) musculoskeletal troubles (Ringen and Seegal, 1995). Holmström and Engholm (2003) also report period prevalence figures for the neck (63.6%), shoulders (66.7%), elbows (42%), wrists/hands (51.8%), upper back (51.7%), lower back (78%), hips (35.1%), knees (65.9%) and ankles/feet (38.7%) among construction workers based on a large sample size (n= 73,631). Cleaners reported musculoskeletal troubles in all body areas except the upper and lower legs, but they particularly reported shoulder (40%), wrist (40%) and low back (40%) troubles in the last 12 months. Kumar and Kumar (2008) cite from the findings of a Danish study (Nielsen, 1995) of the period prevalence of MSDs in female cleaners (n= 1166): neck (63%), shoulders (63%), elbows (27%), wrists (46%) and low back (36%). These are consistent with the current results. Similarly, Woods and Buckle (2005) also report that cleaning tasks affect the shoulders (23%), hands (22%) and low back (43%).

Point prevalence data for plumbers was reported as very high for the knees (83%) but was 17% or less for the other body regions. In a cross-sectional study of construction workers, Ueno et al. (1999) assessed whether a sample of 119 plumbers had musculoskeletal pain in the hands/arms, shoulders and lower back. The prevalence for hands/arms, shoulders and lower back were 15-20%, 20-25% and 50-55%, respectively. The point prevalence data for joiners was 17% or less for all body regions. No studies reporting point prevalence data specific to joinery could be found. Ueno et al. (1999) assessed whether carpenters had musculoskeletal pain in the hands/arms, shoulders and lower back using a sample of 1166. The reported prevalence of hand/arm and shoulder pain was 30-35%, and for the lower back it was 60%. The point prevalence for cleaners in the current study was 30% for shoulders and lower back, and 20% or less for the other body regions. Kumar and Kumar (2008) cites from a Swedish study of 62 cleaners (Kilbom, 1990) that point prevalence was 22%, 33%, 33% and 11% respectively for the neck shoulders, lower back and wrists, and these figures tally with the figures obtained in the cleaners' study.

However, it is difficult to directly associate the prevalence data with musculoskeletal loading due to the measured work tasks as the workers are also likely to engage in other work tasks. For example, the cleaners that use the scrubbing machines also did other cleaning tasks such as sweeping and mopping; joiners that engage in work tasks that required the joiners' workbench also performed tasks without the workbench, and plumbers performed a wide variety of plumbing and fitting work tasks. According to Hildebrandt et al. (2001), in theory, an instrument used to identify risk groups with respect to musculoskeletal disorders, with the aim of taking effective preventive measures, should contain only items that show a prospective relationship with musculoskeletal symptoms. Hence, it was important to evaluate the discomfort data in addition to the prevalence data.

Discomfort data (Figure 3.5) helped to identify reported discomfort specific to the studied work tasks. Plumbers reported very high discomfort ratings in the knees, lower back and neck. Rose (2007) reported from a study where the mean discomfort ratings for body areas were determined from ten plumber fitters that used press jointing machines for pipe fitting. In this study, the mean discomfort ratings for knees and lower back were strong (Borg's CR-10 scale score= 5). The discomfort ratings using the same scale and the same participant group were weak (2) to somewhat strong (4) for the neck, very weak (1) to strong (5) for the arms and moderate (3) to very strong (7) for the wrists. Joiners' WBD data showed high mean discomfort ratings in the wrists, hands and in lower back and cleaners showed a higher mean discomfort rating in the hands and ankles/feet, but unfortunately, no comparable discomfort data were found in the literature specific to joiners and cleaners.

When prevalence and discomfort data (Figure 3.1 and Figure 3.5) were observed, similar patterns could be seen among participant groups. The data indicates an association between the musculoskeletal symptoms and work tasks being carried out by the workers. Studies by Ueno et al. (1999) and Holmström and Engholm (2003) with construction workers report a variation in MSD prevalence across different trades and relate this variation to differences in the levels of physical exposure. If the workers are able to identify these workplace factors for MSD risk, it could help practitioners to develop solutions to reduce work-related MSDs.

The participants in the cleaners' study appeared to have less experience in the job than those in the joiners' and plumbers' studies. They also appear to be changing the cleaning job frequently. Cleaning, whether using basic hand tools or using automated machines is a labour intensive and physically demanding job (Søgaard et al., 1996; Woods and Buckle, 2005) and is mostly performed by people with a low social status and with a low level of education (Woods and Buckle, 2005; Kumar and Kumar, 2008), and these suggest the reasons for the cleaners to have less experience in the job. Unlike cleaners, joiners and plumbers require formal training and the jobs are considered as technical professions, and as such, workers tend to remain in their particular field.

The stage of change questionnaire was used to categorise the process of change (Whysall et al., 2007). According to this (refer Section 2.5.1), all the workers in the three case study areas were in the 'contemplation' stage. It is interesting that cleaners in particular recognised the risks in their work and were contemplating taking action, despite their generally limited experience and education discussed in the literature (Woods and Buckle, 2005). Further detail regarding this is evident from the user-identified risks and requirements. As can be seen in Table 3.4, all of the cleaners suggested that the 'need to lift and carry the dirty water tanks to empty' was a risk factor for MSDs. A comprehensive participatory study by Woods and Buckle (2005) also indicates the ability of the cleaners to identify MSD risks. For example, they reported excessive machine height and weight; poor grip, trigger and lever design; high pressures required to activate controls; awkward location of controls and the lack of feedback when attaching discs as ergonomic deficiencies with respect to the buffing machines that they used. No such studies were found for joiners and plumbers. However, Rose (2007) has shown that six out of ten plumbers that participated in a study linked job factors to the physical problems they had.

Although all of the workers were interviewed separately in this study, many identified similar risks and requirements. For example, 83% of the plumbers mentioned that they 'need methods to prevent having to keep kneeling for long durations'. For them, period and point prevalence and mean discomfort ratings for the knees were relatively high; the period and point prevalence of knee trouble was 83% while the mean discomfort ratings for the knees after one hour of work were 2.33 (SD 1.63) and 2.50 (SD 1.64) for the right and left knees, respectively. Further, 'connecting the pipes and fittings' where the plumbers are required to keep kneeling had a high to very high REBA risk level. These indicate that the plumbers identified the importance of minimising workplace risk factors to reduce musculoskeletal troubles in the knees.

In the case of joiners, they all expressed the need for equipment to lift and/or move heavy objects (materials and equipment). The period prevalence and severity for low back trouble in joiners was 50% and 33% respectively, which they believed was related to heavy lifting and over exertion. Furthermore, the mean discomfort rating for the lower back was 1.50 (SD 1.04). For joiners, the REBA risk levels for the task elements that involved manual handling also varied from medium to high. These indicate that the joiners also identified the importance of minimising the workplace risk factors to reduce musculoskeletal troubles in the back.

Similarly, all of the cleaners identified the ‘need to lift and carry the dirty water tanks to empty’ as a problem, which they related to bending and lifting. For them, mean discomfort ratings were 1.17 (SD 1.13) and 1.17 (SD 0.89) for upper/middle back and lower back, respectively. This task element (emptying the dirty water tanks) showed a high REBA risk level. Direct observations also support the view that ‘emptying the dirty water tanks’ is difficult. These show that the cleaners also clearly understood the importance of minimising workplace risk factors to reduce musculoskeletal troubles in the back. No supporting evidence was found in the literature to indicate this potential link between the user (worker) identified risks and requirements and the discomfort ratings and REBA risk levels for the relevant task elements.

The findings from this study also indicate that all workers, in all case study areas were able to identify risks and suggest requirements for design for the task elements with REBA risk levels greater than (or equal to) medium. It is also interesting that in general, they did not express concerns about task elements with low and negligible REBA risk levels. For instance, ‘scrubbing open areas’ and ‘filling water and additives’, which had negligible to medium REBA risk levels were not identified by the cleaners as problems. However, ‘scrubbing corners and edges’, which had medium to high REBA risk levels and ‘emptying the dirty water tanks’, which had a high REBA risk level were identified as problems by 60% and 100% of the cleaners, respectively.

A similar association was found in the joiners’ and the plumbers’ studies. In the joiners’ study, ‘measurement and marking’, which had medium REBA risk level was not identified as a problem by the joiners. However, ‘material removal and finishing’, which had medium to high REBA risk levels was identified as a problem. For example, 67% of the joiners mentioned the ‘need to eliminate having to apply forces while in awkward postures’, which is a task carried out during ‘material removal and finishing’. In the plumbers’ study, ‘cutting pipes and preparing fittings’, which had medium to very high REBA risk levels, was identified by a relatively smaller percentage of plumbers as a problem, whereas ‘connecting the pipes and fittings’, which had high to very high REBA risk levels, was identified as a problem by the majority of them. For example, the ‘need to eliminate heavy pipe work’ was identified by 17%, whereas the ‘need to eliminate having to apply forces while in awkward postures’ was identified by 83%.

Furthermore, plumbers experienced the highest MSD risk levels compared to cleaners and joiners according to the REBA. Interestingly, the most number of risks and requirements were also identified by them. Therefore, it can be concluded that workers in all case study areas were able to identify risks and user requirements to prevent MSDs for the task elements that showed higher REBA risk levels. It also indicates that the percentage of workers expressing a particular risk or requirement could be used as a basis for prioritising the risks and requirements for design to help reduce work-related MSDs. However, no studies were found in the literature with similar claims.

There were however a small number of notable instances in the study where the workers did not report any risks. For example, in the cleaners' study the task element of 'lowering the brush' had a very high REBA risk level, but only 10% of the workers identified it as a potential risk. The reason for this may be related to the frequency of this operation within a cycle. This task element is carried out only at the beginning and at the end of a cleaning cycle. In the case of the joiners, only 33% of the workers identified 'clamping devices to secure the jobs on the work bench' as a need although not having clamping devises resulted in a high REBA risk. Again, this may be due to the fact that this task was carried out infrequently and was of short duration. In addition, in the plumbers' study, only 17% of the workers indicated the requirement to 'get everything in place before starting the job' to reduce the risk, whereas it resulted in a very high REBA risk level. However, once again, this task was of short duration. A study on the use of data-logging inclinometer, expert observation and self-report methods to assess risk in 50 heavy industry worksites by Teschke et al. (2009) substantiates the above findings. They reveal that self-reports by workers tend to under-report less common tasks, but over-report task durations compared to expert observation methods.

The ratings regarding worker involvement in task design decisions for cleaners were lower (mean= 2: SD 1.4) perhaps indicating less opportunity or ability to be involved in task design decisions than the joiners (mean= 4: SD 2.0) and plumbers (mean= 5: SD 1.0). Low worker involvement in the task design decisions in cleaning may be due to the fact that the cleaners have low levels of experience and education as mentioned by Kumar and Kumar (2008). This is a salient issue also identified by Woods and Buckle (2005). However, the managers themselves in this case were able to bring in their own experience of cleaning in making task design decisions. In the case of both joiners and plumbers, there is a formal training and the perceived experience may be involved in such decisions (Barbash, 1968; Steedman, 1997).

All participants in all three case study areas were able to identify the main risks and requirements for design during the interviews suggesting the potential impact of participatory methods. The favourable culture that participation brings into the work environments by giving responsibility to the workers has been discussed extensively in the literature, for example, Kuorinka and Patry (1995), Kogi (2006) and Rivilis et al. (2008). It will evoke a sense of ownership among the participants to the solutions that will be ultimately implemented and form a basis for lasting solutions and continuous improvement.

3.6.1. Limitations of the study

As mentioned in Section 3.2, four combinations of work characteristics can be derived to cover most environments (i.e. stationary workstation and cyclic work task; stationary workstation and varied work task; variable environment and a cyclic work task; variable environment and a varied work task). Unfortunately, a work task involving 'stationary workstation and cyclic work task' (e.g. assembly task in a production line) was missing from this study. The studied work tasks represent only three of the four combinations of workstation layout and nature of task limiting the ability to generalise the findings to a fuller range of work tasks.

Furthermore, there were only five female workers in the sample of 22 workers and all were from the cleaners' study. According to a study by Woods and Buckle (2005), 89% of a sample of 1550 cleaners was female indicating higher proportion of females involved in cleaning. All participants in the joiners' and plumbers' studies were male and the literature also suggests that these are male-dominated trades. However, this limits the ability to generalise the results. Moreover, the study was conducted with only 22 participants, and this also limits the ability to generalise the findings to a wider worker population. In previous studies to identify musculoskeletal ill-health, large samples of workers have been used. For instance, Atterbury et al. (1996) interviewed 522 carpenters to assess musculoskeletal problems and van der Molen et al. (2009) assessed 914 carpenters and pavers in their study. However, smaller samples have also been used, for example, Woods and Buckle (2006) conducted interviews with 38 cleaners to identify risks and requirements. Woods and Buckle (2005) obtained data from 27 workers in their study of buffing machines, 25 in their study of mopping and 23 in their study of vacuum cleaners to identify requirements for design. Although there were no specific literature to be found related to the study of joinery or plumbing tasks, studies with similar worker groups have been reported. For instance, Ciriello et al. (2007) involved 14 participants in the assessment of pushing and pulling forces to obtain requirements for improvement and van Duijne et al. (2008) used 10 participants to obtain information about the safety aspects of gardening tools. In order to minimise the error due to the small sample size, all the workers in the studied work tasks took part.

The small number of participants (n= 22) and the use of ordinal rating scales does not justify advanced statistical verification of the effects between participant groups (Clason and Dormody, 1994; Annett, 2002; Göb et al., 2007). Ordinal scales were used to assess both worker task design decisions and whole body discomfort (WBD). Despite the small sample sizes, the non-parametric Kruskal-Wallis test could be performed on these data due to the minimum requirement being met i.e. at least three random samples, samples sizes greater than or equal to five and ordinal scales (Anderson et al., 1993). In addition, the Kruskal-Wallis test does not require the assumption of normality and equal variances that are required in parametric tests (Anderson et al., 1993). For the test of independence of the prevalence data using contingency tables, the assumption that the test statistic has a chi-square distribution was not possible in all comparisons due to the fact that there were expected frequencies less than 5 in at least one category. In these instances, Fisher's exact test statistic was also used for verification of comparisons (Anderson et al., 1993).

Appropriate methods depending on the job situation need to be used to assess risk factors for MSDs (Marras et al., 1999; MacLeod, 2003). Buchholz et al. (2008) suggest that self-reports by workers are an alternative to resource-intensive and invasive modes of assessment. However, they conclude that the validity of self-reported exposure assessment has been questioned. As mentioned earlier, findings of Teschke et al. (2009) where they reveal that self-report methods over estimate tend to under-report less common tasks also support this argument. In addition, in order to help verify the information elicited from the workers, multiple methods could be used (Stanton et al., 2005). Hence to collect data, a number of methods such as direct observations, REBA and WBD were used.

With regard to posture analysis, efforts were made to control the camera angles to capture the joint angles. However, this was difficult in practice and the REBA scores had to be based on estimations of the joint angles. REBA risk levels are defined for a range of REBA scores, which minimises the error due to camera angles. Moreover, perfect maintenance of camera angles is difficult to achieve in the field setting. Issues related to posture-based methods (including REBA) are extensively discussed by in a review by Li and Buckle (1999a) and however conclude that, although there are limitations in these methods, they are being widely used by practitioners. Dempsey et al. (2005) also suggest that risk assessment tools such as REBA are popular among practitioners supporting the use of REBA in the current study.

The findings suggest that the line managers of cleaning, joinery and plumbing staff were in the maintenance stage according to the stage of change categorisation scheme indicating a worker-conducive environment with respect to minimising work-related MSDs within the organisation. However, Whysall et al. (2007) suggest that managers may exaggerate their involvement in workplace improvement and worker involvement in task design decisions when asked about interventions. In the current research, information provided by both workers and managers in individual interviews regarding stage of change were in congruence. It is impossible to decipher if this is an exceptional organisation with good communication between line managers and workers, and thereby limiting the applicability of findings to wider range of organisations.

3.7. Summary

Musculoskeletal troubles were reported by workers in all three case study areas (cleaners, joiners and plumbers) with the majority reporting significant symptoms. From the interviews it was apparent that all workers were able to identify risk factors in their job for work-related MSDs, and the main requirements for design to reduce such risks. These were mainly related to frequently occurring manual handling, awkward postures, prolonged exertion of forces and maintenance of postures. Further analysis by the researcher led to prioritised lists of user identified risks and requirements for design for the three case study areas.

Direct observation techniques enabled the verification of the worker-identified risks by using standard techniques such as rapid entire body assessment (REBA). In addition, direct observations were used to add further detail for example, estimations of physical properties such as loads and dimensions. Interviews with workers together with direct observations are potentially useful methods for practitioners in the field.

All managers reported obtaining worker-feedback when making task design decisions. This indicates that they recognise the importance of worker experience to potentially help reduce work-related MSDs. However, joiners and plumbers reported higher involvement in the task design decisions than the cleaners indicating different levels of participation in the design process.

4. Development of the design tool

4.1. Introduction

As discussed in the literature review (refer Section 2.4), participatory approaches have been effective in improving working conditions. However, practitioners, for example, designers, engineers and ergonomists in general are not involved in all participatory steps creating a mismatch between user requirements and what is present in designs. It was also identified that methods and tools for user participation are important to support practitioners in collaboratively identifying user requirements. As a first step, the knowledge and ability of users (workers) to identify workplace risks and the subsequent requirements for design in order to reduce the risk factors for developing MSDs were evaluated (refer Chapter 3). Further tools and techniques are required to effectively facilitate communication of user requirements and other relevant design information in the design process and bridge the gap between the users (workers) and the practitioners of design. Quality function deployment (QFD) has been identified as a potential approach to facilitate communication in the design process.

Thus, research was conducted to develop a QFD-based design tool to facilitate communication in the design process to help reduce work-related MSDs (refer Chapter 1: Objective 2). It focuses on bridging the gap between the users (workers) and the practitioners of design. This chapter discusses the process of development of the design tool.

In this pursuit, the following sub-objectives were considered:

- To explore the feasibility of QFD as a basis to develop a collaborative design tool to facilitate communication among the stakeholders in the design process;
- To identify key features of the design tool;
- To explore tools and techniques to guide practitioners in the design process to help reduce work-related MSDs.

4.2. Quality function deployment (QFD)

QFD can be thought of as a methodology that ensures compliance of the design features of products or processes with the user requirements. This is achieved by effectively and efficiently managing the information required for design (that includes user requirements) throughout the planning, designing and production processes: planning is determining what to produce; designing is deciding how to produce it; and production is the process of realising the product (Akao, 1990). Designing and manufacturing ideally need to be preceded by planning in order to make designs successful (Akao, 1990). For this, QFD uses techniques such as ‘house of quality’ as discussed in Chapter 2, and it is said to minimise the product development time, cost of designing and the cost of subsequent operation.

4.2.1. Industrial applications of QFD

A review by Chan and Wu (2002) identified that QFD has been successfully applied to a variety of industry sectors (e.g. transportation, software systems, manufacturing, aerospace, agriculture, construction, disaster prevention, environment protection and military). They discuss its capability as a design method that can be conveniently fitted into different contexts. It has been used for a range of purposes that includes product development, quality management, customer needs analysis, planning and decision making, team-working, timing and costing in these industries. The emphasis on deriving requirements from the users themselves and spanning across phases of planning, designing and manufacturing makes it a useful tool.

Interestingly, the application of QFD is also reported in the literature related to ergonomics (summarised in Table 4.1). For example, Bergquist and Abeysekera (1996) discuss the use of QFD in developing safety shoes. It has been used to develop a usability assessment model to assess overall sensation, detail sensation, usability evaluation and physical design factors of products based on rating scales (Jin et al., 2009). Guedez et al. (2001) suggest its use in developing both products and processes that conform to user requirements.

Although the literature concentrates on the application of QFD tools for the development of particular products, the authors have not attempted to generalise the methods as part of a design approach. However, they agree that QFD is a feasible method to ensure that ergonomics criteria are considered as part of good design. For example, Marsot (2005) suggests QFD as a methodological tool for the integration of ergonomics in design and greater consideration of ergonomics. Table 4.1 has been specifically used to appraise the published articles on QFD based on the methods used within QFD, the simplification of QFD, the use of the methods as generalised tools for different contexts and the impetus that the articles provide to use QFD as a generalised tool to help design.

Table 4.1. Reported application of QFD in ergonomics and related areas

Authors	Application area	Use of QFD tools	Critique
Bergquist and Abeysekera (1996)	Safety shoe design for cold climates	User requirements (questionnaire); prioritise (rating scales); relationship matrices; target values (standards); correlations (+ and – effect relationships between product characteristics); prioritise product alternatives (weighting of product characteristics and user needs).	Considers QFD as a means of developing usable products. Questionnaires to determine user requirements limits the breadth and depth of understanding about the requirements as the questionnaire is developed according to researcher understanding and may not include vital aspects of the product. Rating scales to prioritise user requirements needs prolonged involvement of the users, perhaps unnecessarily. Used a QFD matrix to translate requirements into product characteristics for a single product, but has not considered the work task that required the safety shoe as a whole. Researcher opinion has been used to determine product characteristics, but does not show how these were identified. Used the numerical weighting system of original form of QFD to assess product characteristics. Technical and customer analyses have not been carried out due to lack of available information.
Haapalainen et al. (1999/2000)	Non-powered hand tools (pruning shears)	User requirements (questionnaire, focus group); prioritise (rating scales); design parameters (using ergonomics literature); product comparison (by experts using numeric scales); relationships matrices.	Consider QFD as a suitable method for ergonomic design of hand tools and provides reliable results. Used a QFD matrix to translate requirements into product characteristics for a single product, but has not considered the work task that required the pruning shear as a whole. Rated the importance of user requirements by comparing different pruning shears, thus not appropriate for developing new products. Limits the solutions space as only solutions in literature are considered. Used the numerical weighting system of original form of QFD to assess the products.

Authors	Application area	Use of QFD tools	Critique
Parkin et al. (2000)	Fireman's safety harness	User requirements (interview); prioritise (questionnaire); categorise (affinity diagrams); competitive analysis (rating scales); identify solutions (brainstorming); compare products (by experts using numeric scales).	Considers QFD only as a product development tool. Users involved in two stages to identify and prioritise user requirements, which may be difficult in the industrial setting. Compared competitor products to analyse the product, thus this approach is not suitable for new products. Specific information is not given regarding how the solutions were obtained. User involvement needed to complete the relationship matrix. The original form of QFD has been used, which limits the ability to accommodate the flexibility required in the design process.
Guedez et al. (2001)	Small containers	Prioritise user requirements (rating scales); identify solutions (dimensional, postural, lifting analysis and machine performance); relationship matrix (by experts using numeric scales); compare products.	QFD helps to analyse the customers' desires and generate high quality products and processes. Possible to link the desires with solutions in design. Does not show how the user requirements were obtained. Compared different products to prioritise, which does not facilitate developing new products. Considered design principles (delete, simplify, combine and change sequence) in a limited fashion to determine design solutions. Considers only product development and does not mention the work task involving the product.
Fogliatto and Guimaraes (2004)	Toll booth design	User requirements (quantitative-objectively measured and qualitative-expert opinion, alternative products); prioritise (ordering); relationship matrix (by experts	A stepwise guide to obtain workstation components. Components prioritised based on their impact on users' demands, optimising resource allocation. Used interviews to obtain user requirements. The order in which the participants spelled out the requirements were used (adding the order priority numbers) to judge the importance of them, which is a numerical operation on ordinal data. Does not provide details on how the

Authors	Application area	Use of QFD tools	Critique
		using numeric scales).	product characteristics were decided. Original QFD approach, with numerical estimates of relationships was used to complete the relationship matrix, and a numerical approach is followed throughout, which may not suit the design process especially in the early stages. Considers only product development and does not mention about work tasks involving the product.
Marsot (2005)	Boning knife	User requirements (interviews, observations); prioritise (*AHP); identify solutions (expert analysis); correlations.	Suggests QFD as a methodological tool for the integration of ergonomics at the design stage geared to greater ergonomics consideration in product design. Used AHP, which needs a lot of involvement in the part of the researchers and users. Used conceptual virtual designs to analyse, which may not always be feasible in practice. The original form of QFD with numerical estimates of relationships was used, which limits the ability to accommodate the flexibility required in the design process. Considers only product development and does not mention about the work task that involves the product.
Kadefors (2007)	Workstation design	User requirements (knowledge of the users, force, posture and time demand); design parameters (scientific knowledge, user information).	An opinion paper. Workstations may be designed using a methodology based on QFD taking into account musculoskeletal stressors (load, posture and repetition). Provides guidance on how to use a QFD approach to develop workstations and concludes that decision support systems will enable practitioners to have access to all relevant data needed for design.

Authors	Application area	Use of QFD tools	Critique
Jin et al. (2009)	Usability evaluation model	Analyse four aspects of the evaluation model (overall sensation, detail sensation, usability evaluation and physical design factors); evaluate the different factors (ratings and quantitative techniques).	Presents a usability evaluation model based on customer sensation using QFD, which evaluates the relationship between consumer sensations and usability among the physical design factors. Compares design parameters and the sensation factors to evaluate usability of products, but sticks to the original form of QFD where numerical estimates are used, which prevents it from being used equally well in all stages of the design process. Does not give the approach used to determine design guidelines based on the usability sensations. Does not indicate whether the approach is appropriate for processes in addition to products.
Kuijt-Evers et al. (2009)	Hand tools	User requirements (early studies); prioritise (rating scales); solutions (experts); relationship matrix (by experts using numeric scales); evaluate solutions (users).	QFD is effective in integrating ergonomics needs and comfort into hand tool design. Does not explain how the engineering characteristics were determined by the experts. The original form of QFD with numerical estimates of relationships was used, which limits the ability to accommodate the flexibility required in the design process. Also conclude that design team's correlation estimates are not as accurate as generally assumed questioning the inclusion of the numerical estimates of the relationships. Considers only product development and does not mention work task that involve the product.

* AHP- Analytic hierarchy process (Saaty, 1980; 1990)

Furthermore, the research studies listed in Table 4.1 have frequently used interviews, questionnaires, observations and focus groups to identify user requirements and solutions. However, consideration of risk factors for MSDs is not always apparent and these also need to be addressed when developing solutions. Interestingly, Marsot (2005) and Kadefors (2007) suggest consideration of musculoskeletal problems when addressing user requirements indicating that QFD may be used in assessing requirements related to minimising MSDs. For instance, Kadefors (2007) suggests considering force, posture and time demand in the process of determining solutions.

Studies in Table 4.1 also show that researchers have used the computational techniques recommended in QFD related literature to prioritise user requirements, for example, rating scales and the analytic hierarchy process (AHP) (Saaty, 1980; 1990). It may be impractical to use these lengthy methods in the industrial setting given potentially large worker numbers and the demand for a high work pace. More feasible methods of prioritisation are needed that minimises user involvement.

Table 4.1 further suggests the use of different techniques to identify design solutions. For instance, Marsot (2005) suggests brainstorming; Bergquist and Abeysekera (1996) suggest the use of manufacturer information or the knowledge of production engineers and Haapalainen et al. (1999/2000) advocate the evaluation of other products for the same task. However, these studies do not reveal the use of any techniques that entice innovation. Guedez et al. (2001) mention that fundamental principles suggested by Ishiwata (2000), i.e. to delete processes if possible, simplify them, combine them and change their sequence were used to guide the improvement of processes. Such efforts could be useful in the development of the design tool since they possess expertise in different areas useful to ferret out innovative design solutions.

The studies presented in Table 4.1 also show that researchers have always adhered to the original QFD house of quality matrix based approach. In QFD matrices (see Figure 2.6), the user requirements are related to each of the established solutions using numerical estimates determined by design teams. These are known as correlation estimates in QFD terminology and are used as multipliers to determine the importance of each of the solution according to their ability to satisfy the user requirements. From their study of hand tools, Kuijt-Evers et al. (2009) found that the design team's correlation estimates between user requirements and solutions are not as accurate as is generally assumed. This is a basis to question the approach of using multipliers based on rating scales in the relationship matrix to determine the importance of solutions (Burke et al., 2002). Kuijt-Evers et al. (2009) further suggest that user evaluations may provide better results in this regard. This hints that it may not be practically feasible to use the original house of quality matrix to enhance communication among stakeholders of the design process due to the time and effort required by the stakeholders of the design process to complete it, and ideally, stakeholder involvement should be minimised to comply with industry demands and to ensure sustained stakeholder interest.

In essence, the use of QFD together with related appropriate tools is feasible as an approach to develop a design tool that integrates the different phases of the design process to help practitioners consider ways to reduce work-related MSDs. However, the QFD process has to be simplified in order to be effective and efficient in the proposed context. Consequently, research is required in this regard to determine the tools and techniques that may be used with QFD.

4.2.2. Variants of QFD

Based on a comparison of 16 projects (that included both successful and unsuccessful projects), Herzwurm et al. (1998) discuss the success factors of QFD and suggest that high product complexity does not reduce the value of QFD. Further, the authors suggest recommendations for the design of QFD projects. They specifically mention that the involvement of employees in the QFD process is necessary, because communication/collaboration would be then ensured at every stage. They also suggest that structured project organisation, project specific adjustment of QFD using supplementary methods and detailed analysis of the relationships between requirements and solutions are vital.

In this light, simplification of QFD using techniques to improve its utility is vital for its successful implementation in the field setting. Interestingly, one of the useful features of QFD is its ability to integrate with other methods to enhance its use. For example, Aldrich and Stauffer (1995) suggest the use of the house of quality with a database to access source data. In addition, Iranmanesh et al. (2005) report on the integration of a value analysis method to design parameter estimation to improve customer perception. It may be possible to obtain promising results if appropriate methods are used to reduce the complexity of QFD. Furthermore, they suggest the importance of having the capability to identify design parameters or solutions and making use of existing design information through database support.

Several methods have been used to obtain a satisfactory set of design parameters through the original QFD process such as fuzzy logic and genetic algorithms (Bouchereau, 2000; Bai and Kwong, 2003; Chen et al., 2006). Techniques such as fuzzy logic and genetic algorithms involve mathematics and computer programming to deliver results. They are capable of handling large amounts of information, which may be difficult to manage manually. They have wide applications in fields such as artificial intelligence, advanced manufacturing, robotics and optimisation. However, a design tool to enhance collaboration among the stakeholders in the design process is unlikely to be helped by techniques that require advanced mathematics. In reality, in the early stages of the design process, the most vital part is to map the user requirements with appropriate solutions. What is important in these stages is the involvement of the stakeholders in the design process and methods to encourage this.

Furthermore, there have been previous attempts to devise software tools to facilitate the QFD process by integrating different phases of the design process (Herzwurm et al., 1997; Rawabdeh et al., 2001; Herzwurm et al., 2003). These provide an indication of the capability of QFD to be a computer based approach. This review also provides a strong justification for choosing QFD as a basis to develop the proposed design tool. However, simpler concepts, tools and techniques that can deliver pragmatic results in the field setting need to be explored. Thus, selected features of QFD coupled with other tools that potentially support design may effectively be used to help practitioners not only to identify risks and user requirements, but also to systematically provide acceptable design solutions to reduce work-related MSDs.

4.3. Scope of the design tool

Practitioners involved in the design process include such as ergonomists, human factors engineers, occupational health and safety personnel, engineers and designers. The design tool intends to bridge the gap between the users (workers) and these practitioners to ensure that requirements to reduce workplace risk factors for MSDs are reflected in the products and processes being designed, through effective and efficient communication among the stakeholders. This should be made possible by enabling all stakeholders to visualise important information required for effective design. Importantly, the proposed design tool is in accordance with the participatory process and design models discussed in literature (refer Sections 2.4 and 2.6). This design tool would also promote the model of synergy between health promotion and design proposed by Mayfield and Hill (2007) (refer Section 2.5).

4.4. Description of the design tool

As mentioned earlier, QFD is essentially a quality engineering tool that facilitates the design process by adding structure to it. It is neither a tool to obtain requirements for design nor a tool to create ideas to suggest solutions (León-Rovira and Aguayo, 1999), but it is an approach to help identify and manage design information that includes both requirements for design and solutions to address the requirements. Thus, use of QFD would make it possible to integrate the phases in the participatory process, and help manage design information. The design tool based on QFD is an approach to manage design information and to enhance communication among the stakeholders of design involved in reducing work-related MSDs. Once the design information is established through collaboration, it can be used to further analyse, synthesise and develop solutions to reduce work-related MSDs. In this pursuit, a design tool that consists of six related features was developed based on the literature on participatory processes, design models and QFD. The tool is illustrated in Figure 4.1.

As discussed throughout this thesis, identifying and specifying requirements for design is of utmost importance for successful design, and the design process starts with this phase. For example, the 9-step participatory process (Vink et al., 2008) starts by planning and studying the experienced problems in order to identify risks and obtain requirements. In line with Archer's design model (Cross, 1994), the data collection phase signifies the importance of identifying requirements for design. Thus, both QFD and participatory ergonomics processes (refer Section 2.4) emphasise the importance of the involvement of workers (users) in the design process to obtain requirements for design. The user requirements study presented in Chapter 3 further showed the knowledge and ability of workers to identify risk factors in their workplaces for MSDs and specify requirements to potentially reduce such risks. Hence, the function of the first feature of the design tool was to guide practitioners in 'identifying risks and obtaining user requirements' to help reduce work-related MSDs.

In order to help practitioners develop solutions to better suit the users, more important requirements need to be given higher priority (Cross, 1994). For this, the relevant data has to be analysed and prioritised to determine design objectives. For instance, Barnes and Lillford (2009) discuss the prioritisation of user needs according to user evaluations in the context of a decision support framework for effective product development. Interestingly, QFD also acknowledges the importance of prioritising user requirements (Akao, 1990; Terninko, 1997). The literature on QFD further advocates user involvement in prioritising such requirements to help identify solutions that conform to user needs (e.g. Day, 1993; Terninko, 1997). Therefore, the second feature of the proposed design tool was 'prioritising the risks and user requirements' to help practitioners to determine importance of each of the requirements for design.

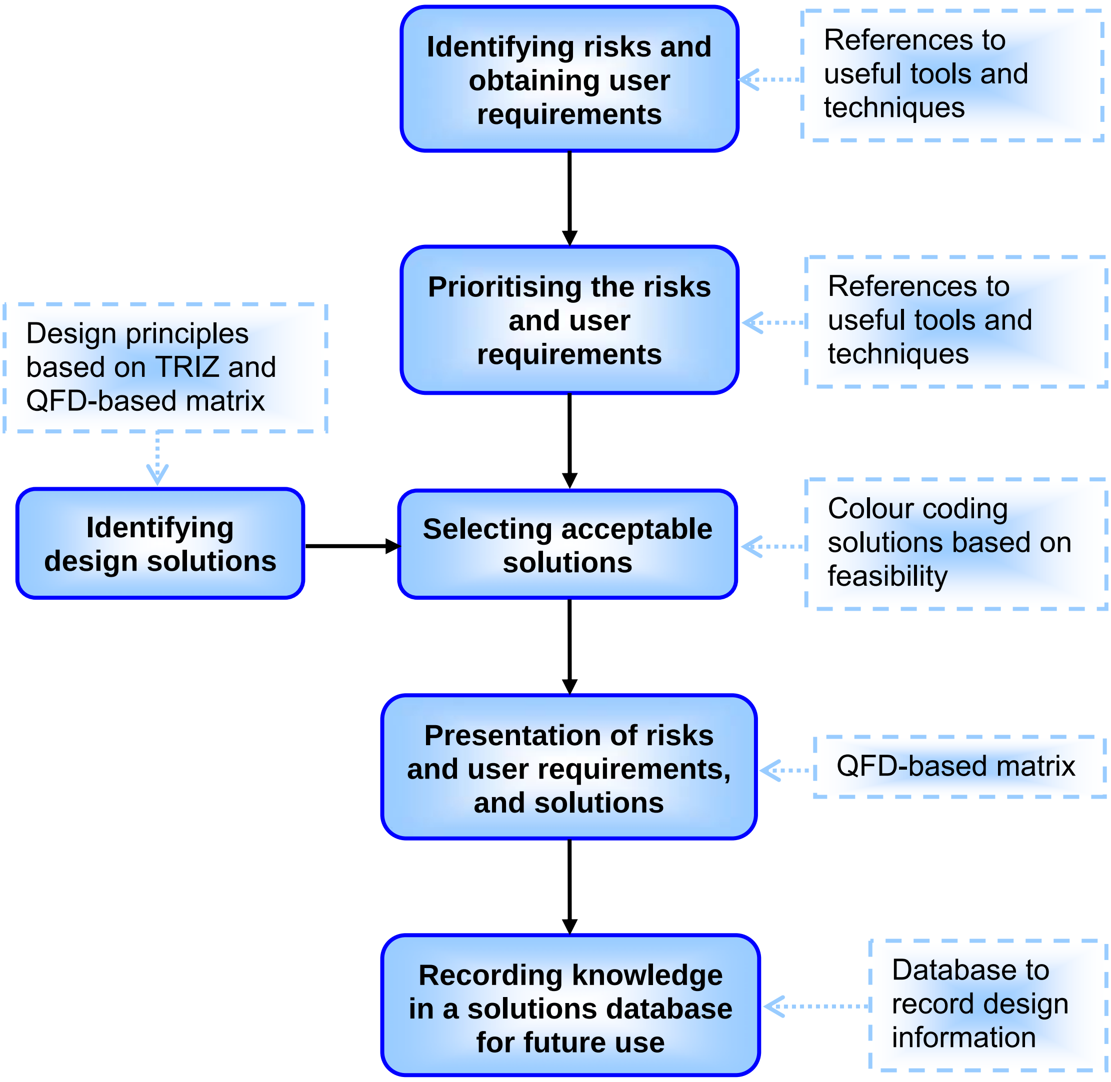


Figure 4.1. The features of the design tool (and guidance) for practitioners to help reduce work-related MSDs

Then, solutions need to be identified for the prioritised requirements for design. The effectiveness and efficiency of identifying solutions is important because stakeholders in the design process possess different levels of knowledge and capacities with respect to design. In addition, it would make an environment conducive to collaboration. The literature on QFD also highlights identifying design solutions as an important aspect of the design process (e.g. Terninko et al., 1998). As a result, the third feature of the design tool would focus on 'identifying design solutions' and assist stakeholders in suggesting design solutions to tackle the workplace risk factors for MSDs.

Following this, the solution space needs to be reduced to obtain feasible/acceptable design solutions to address the requirements. This would allow practitioners to distinguish the feasible solutions to carry forward in the design process for further development. For this, practitioners need to use different criteria. This is a key aspect considered in the literature. For instance, both the 9-step participatory process (i.e. idea selection phase) and Archer's design model (i.e. analysis phase), which were also discussed in Chapter 2, involve selecting acceptable solutions from the identified possible solutions. Thus, it was decided that 'selecting acceptable solutions' would be the fourth feature of the proposed tool.

For effective communication among the stakeholders in the design process, clear presentation of design information is of utmost importance. This is a key contribution of QFD where it supports visualisation of all relevant design information and helps to ensure that it is passed down and made available to subsequent stages of the design process (Akao, 1990; Day, 1993). It is important to visualise design information such as prioritised risks and user requirements, acceptable design solutions, observational data, standards, guidelines and regulations to facilitate communication. Therefore, the fifth feature of the design tool would be to facilitate 'presentation of risks and user requirements, and solutions'.

As discussed earlier, utilisation of databases to help record design knowledge pertinent to QFD is discussed in the literature (Aldrich and Stauffer, 1995). This knowledge acquired from one project can be conveniently harnessed in identifying design solutions in other related projects. This would also help continuous improvement of the equipment and processes being developed, which is also an important aspect considered in QFD. Moreover, it would help to share information, knowledge and resources from different design projects, and would facilitate both collaboration and communication among the stakeholders. Consequently, the sixth and final feature of the design tool would focus on guiding the practitioners to 'record knowledge in a solutions database for future use'.

4.5. Elements of the design tool

The literature review was extended to identify appropriate tools and techniques that could be used to support practitioners using the proposed design tool. MacLeod (2003) in a review discusses the effectiveness of ergonomics methods and concludes that future methods should facilitate amalgamation of results from many different methods throughout the design and development life cycle of a system. Hence, this review focused on methods that could be integrated with QFD. The identified tools and techniques helped develop the guidance material to help practitioners in the design process. Following is a discussion of the literature pertinent to each feature of the design tool.

4.5.1. Identifying risks and obtaining user requirements

Tools and techniques available to explore workplace risk factors of MSDs and extract user requirements that would potentially reduce workplace risk for MSDs were reviewed. A key expectation of this design tool was to involve users (workers) as much as possible in the process of elicitation of risks and user requirements. Therefore, tools and techniques that promote participation were given priority.

Questionnaires, interviewing users, observing user behaviour, searching for visual inconsistencies, data logging, data reduction and literature searching are suggested by Cross (1994) to help explore design situations. In addition, Popovic (1999) provides a list of specific tools that includes simulation and virtual reality (VR), mock-up evaluation, prototype evaluation, checklists, focus groups, observation techniques, protocol analysis and task analysis. Furthermore, Bergquist and Abeysekera (1996), Haapalainen et al. (1999/2000) and Marsot (2005) suggest methods such as needs functional analysis and video observations to obtain requirements for design. All these methods may be categorised under qualitative techniques. These qualitative approaches of data collection are now briefly discussed in terms of their suitability in the different contexts under which practitioners are required to collect data.

Questionnaires can be used successfully to derive risks and user requirements (Kuorinka et al., 1987; Motamedzade et al., 2007; Lawton et al., 2008). For instance, the standard Nordic musculoskeletal questionnaire (Kuorinka et al., 1987) can be used to assess prevalence and severity of MSD symptoms, and use this information to identify risks for MSDs. In addition, bespoke questionnaires can be developed to cater for individual needs (Oppenheim, 1966; Flick, 1998). Using questionnaires, it is possible to obtain user requirements from a wide spectrum of users, but the problem lies with the response rate (Creswell, 2007; Saunders et al., 2007). Further, it is not possible to collect all required information for design using questionnaires (Oppenheim, 1966; Flick, 1998; Stanton et al., 2005). Reasons for this include, questions are not always simple and straightforward; no opportunity to probe and get further information; all the questions could be seen before answering; the researcher cannot identify whether the intended person is answering; inability to screen respondents and inability for the researcher to supplement answers by observational data.

According to Courage and Baxtor (2004), an interview is a guided conversation in which one person seeks information from another. The three main types of interviews are structured, semi-structured and un-structured (Stanton et al., 2005). Interviews can be used to obtain detailed information from users (Carlin, 2009). It is also possible to obtain an overall view of the user requirements by interviewing a number of users. Discussions on interviewing techniques are available in literature (Flick, 1988; Bouma and Atkinson, 1995; Stanton et al., 2005; Creswell, 2007). There are shortcomings in interview techniques as well. They can be biased if incorrect techniques are utilised, for example, Jaszczak et al. (2009) discuss that inadequately trained interviewers could affect data quality. However, to gather risks and user requirements, interviews may be conveniently used if the shortcomings are minimised (i.e. if proper guidance is provided).

Instead of using individual interviews, it is possible to employ group interview methods commonly known as focus groups to gather risks and user requirements. These have been used vastly in ergonomics with success. For example, Pehkonen et al. (2009) have used focus groups with other techniques in a participatory ergonomics intervention process to improve kitchen work and report that 402 improvements in all were made. However, use of group interview techniques in present industrial environments may prove to be difficult because organisations tend to utilise an optimal number of workers at work at a given time. Furthermore, in a study on deploying users to derive user requirements in a collaborative manner using a focus group techniques (Bruseberg and McDonagh-Philp, 2002), experts were sceptical about their effectiveness. Although there are identified shortcomings in implementing focus group techniques (Stanton et al., 2005), it can be listed as a resource to support practitioners to obtain risks and requirements from users (workers).

Observation techniques can involve direct investigation of user behaviour, video observations, data logging and data reduction (Pinzke and Kopp, 2001). Konz (1990) describes different methods of collecting observational data on work tasks such as the work element recording checklist. There are also other checklists (refer Section 2.4.2) that could be used in participatory approaches to help improve workplaces, for example, the ergonomic checkpoints (ILO and IEA, 1996). One drawback of checklists is that, they may limit the ability for the practitioners to obtain detailed information from workers. Nevertheless, checklists are popularly used by practitioners. However, these provide an opportunity to investigate about the material culture and the space (O'Toole and Were, 2008) in the industry. One significant advantage of conducting observations is the flexibility it offers to the observer. Another advantage is that direct observations can be supported by video recordings and still photographs as a memory aid. In addition, experts can combine their experiences to obtain rich data, although care must be taken not to introduce bias. Observation techniques have another drawback as a possible change in participants' behaviour (Hawthorn effect) may occur when being observed (Harvey et al., 2009).

The following risk assessment techniques can also be considered as checklists because they guide practitioners step-by-step to obtain the required information. There are standard posture recording techniques for MSD risk assessment such as Ovako working posture analysis system (OWAS) (Karhu et al., 1977); posture, activity, tools and handling (PATH) (Buchholz et al., 1996); rapid upper limb assessment (RULA) (McAtamney and Corlett, 1993); rapid entire body assessment (REBA) (Hignett and McAtamney, 2000); quick exposure check (QEC) (Li and Buckle, 1999b; David et al., 2005; David et al., 2008), and NIOSH lifting equation (Waters et al., 1993). In addition, tools such as the whole body discomfort map (Corlett, 1990) can be conveniently used to quantify the discomfort experienced by the workers for comparison with posture recordings. In addition, some of the tools are based on previously developed techniques with added features. For example, RULA was the basis for the development of REBA (Hignett and McAtamney, 2000). REBA has an added feature to accommodate dynamic situations in the assessment of MSD risk (David, 2005) while both these techniques have a similar format to record and determine the risk. A review by David (2005) states that these techniques are inexpensive and practical, but the scoring systems are largely hypothetical, and this emphasises the problem of determining the validity of such methods. However, they are being used to quantify the risk of MSDs although their popularity differs among practitioners (Dempsey et al., 2005). Practitioners can be provided with a list of commonly used posture recording techniques to guide them in the process of understanding risks and user requirements. Risk assessment techniques can be selected by practitioners according to their particular requirements, for example, as presented and discussed in Section 3.3. For example, REBA was selected in the user requirements study (refer Chapter 3) to suit both static and dynamic work situations and to collect data without the involvement of the workers.

Standards and guidelines may also help to identify requirements for design and add design details for equipment, facilities, procedures and training. These are available from different sources such as the British Standards Institute (e.g. BS 3044 and BS 527), international standards (e.g. EN1005, EN ISO 9241, EN 547 and EN ISO 15536), design handbooks (e.g. Chengalur et al., 2004; Karwowski, 2006), government bodies and authorities (e.g. Department of Trade and Industry, 1998; Luttmann et al., 2003; HSE, 2003; OSHA, 2004; DSTAN, 2009). Guidelines to help reduce work-related MSDs are also available widely in the literature. For example, Devereux (2005) suggests that at least four hours of keyboard work a day appears to increase the risk of neck/shoulder and hand/wrist MSDs about two-fold compared to little or no keyboard work. Muggleton et al. (1999) cites from a publication by Hammer (1934) that, as a rule of thumb, human tendons will not tolerate more than 1500-2000 manipulations per hour. They also cite from Wilson (1983) that tenosynovitis can develop even with light objects if manipulations are more than 1000 per day. These standards and guidelines are compiled and published by researchers and organisations, for example, Mital et al. (2000) published a book on ergonomics guidelines and problem solving.

Both standards and guidelines are mainly based on scientific experimental studies (Viikari-Juntura, 1997). Therefore, the results will always be dependent on the context of the experiments. Validity of such experiments is debatable, given that the levels of the variables are usually not constant in real life situations, and justified based on assumptions. Consequently, if the standards and guidelines proposed through such studies are used directly in design, it may give rise to unexpected problems. Hence, they may need to be adapted to suit different situations in the industry (Denis et al., 2008). For particular situations, published standards and guidelines may not be applicable at all. Involving workers in the design process may help practitioners in selecting, adapting or by-passing standards and guidelines to suit real life applications. In addition, information in the literature changes continuously as it is the nature of such information (Courage and Baxter, 2004) and practitioners need to be up-to-date in order to be effective. Compendia of standards, guidelines and specifications etc. such as the handbook of standards and guidelines in ergonomics and human factors (Karwowski, 2006) may help practitioners in this regard. Therefore, reminding practitioners to refer to relevant standards and guidelines in order to help them establish risks and user requirements is important.

Qualitative approaches in general have inherent challenges. For example, Dickson-swift et al. (2007) reports on challenges such as rapport development, use of researcher self-disclosure, feelings of guilt and vulnerability and leaving the research relationship. In addition, Bowen (2008) questions the determination of saturation point to terminate the data collection process. In addition, use of a single method to identify risk and obtain user requirements may expose the limitations of that particular method. This could be negated if multiple methods are used to elicit information (Saunders et al., 2007). Furthermore, the use of multiple methods research would help obtain richer data in terms of breadth and depth and help confirm or corroborate information elicited by way of triangulation (Moran-Ellis et al., 2006). Techniques of mixed methods research (i.e. combining qualitative and quantitative techniques) could also be used to reduce the biases that may creep in when only single methods are used (Johnson et al., 2007) and help quantify the elements that are identified using qualitative techniques.

When techniques for user evaluation and risk assessment are analysed they all have a common shortcoming: they are not directly linked with any other methods to streamline the process of providing solutions to the problems identified from the workers. For example, the REBA technique is used to assess MSD risk, but is not combined with any other method to provide solutions to the identified risks. As a result, independent use of such tools does not help practitioners to identify appropriate solutions to reduce MSDs. It may be useful if methods throughout the design process are integrated to help effectively communicate the requirements to the designers.

Streamlining this entire process and integrating different methods could rectify this shortcoming. QFD is potentially helpful in communicating the requirements for design together with other relevant design information to the subsequent phases of the design process. Therefore, based on the above discussion, it was decided to include a list of useful methods that could start to help different stakeholders in the design process to identify risks and obtain user requirements. The semi-structured interview guide (Appendix 3.3), observations proforma (Appendix 3.4), REBA recording form (Appendix 3.5) and the WBD scales (Appendix 3.6) that were used in the user requirements study were decided to be linked to the guidance material provided in the design tool for the practitioners. Furthermore, web links of suitable tools and techniques and relevant standards and guidelines were planned to be included.

4.5.2. Prioritising the risks and user requirements

Various strategies can be used to prioritise the risks and requirements for design. For example, the 9-step participatory process (Vink et al., 2008) advises that 'impact on productivity and health' is an important priority for design. Techniques such as thematic analysis (Ryan and Bernard, 2003; Ryan and Haslegrave, 2007; Meyer and Avery, 2009), content analysis (Erlandson et al., 1993; Creswell, 2007; Teddlie and Tashakkori, 2009) and Experience-based judgments can be used to analyse the impact of risks and requirements for design on productivity and health. The constant comparative method (Glaser, 1965; Glaser and Strauss, 1967; Lincoln and Guba, 1985; Boeije, 2002) together with frequency analysis can also be used to first define and then prioritise requirements identified by different respondents to obtain a prioritised list for design. Here, themes identified by one respondent are compared with the themes identified by the previous respondents, and prioritised based on the number of times a particular theme is present across the total number of respondents. These prioritisation techniques in general do not require worker participation.

Various other techniques can also be used to prioritise the identified risks and user requirements. Rating scales (Griffiths et al., 2006) is a technique where requirements for design are rated by respondents (Table 4.1). However, the use of rating scales is arguable because the ratings are prone to bias due to subjective nature of human judgement (Annett, 2002). Analytic hierarchy process (AHP) suggested by Saaty (1980; 1990) uses repeated pair-wise comparisons of requirements to obtain a prioritised list. Although priorities can be represented on a ratio scale and hence considered as a versatile method, the process takes time and effort on the part of both users and practitioners. Wants and needs analysis also provides information about the kinds of content, features and characteristics users require in a product (Courage and Baxtor, 2004). This is a brainstorming activity, which results in a prioritised list of user requirements, and is most beneficial during the conceptual design stage of a product for both evaluating existing features and learning about new features. Techniques such as protocol analysis (Ryan and Haslegrave, 2007) and task analysis (Stanton, 2006) may also be successfully used to analyse user requirements. Extensive worker and practitioner participation is essential for the success of these methods, which may be difficult with current time demands in the industry.

The feasibility of these methods depends on the context and convenience of use, and practitioners may need guidance in order to select those appropriate for a given application. In addition, the cross-checking of prioritised lists of requirements for design needs consideration to ensure validity. Thus, in any guidance material, the methods proposed as useful should be categorised, for example, content analysis and Experience-based judgements. Therefore, in order to help the practitioners with content analysis and to help identify priorities, a Microsoft® Excel-based tool was planned as part of the tool. A concept based on the constant comparative method where similar themes identified by different participants could be listed in rows and the priority values based on the number of participants identifying a particular theme was used. A step-by-step procedure of this approach and a screen shot of the Microsoft® Excel-based tool is provided in Appendix 4.1. In addition, web links and references were planned to be included for other listed methods.

4.5.3. Identifying design solutions

After the requirements for design are prioritised, solutions need to be determined. Solutions can be determined using the experience of the users and practitioners, but it may limit the possibility of identifying creative solutions that are both effective and efficient. Therefore, this element of the design tool should encourage creative thinking to help identify innovative solutions to reduce workplace risks for MSDs. In order to search for ideas, Cross (1994) suggests brainstorming, synectics and morphological charts as approaches that could be used to generate creative ideas. Brainstorming helps generate innovative solutions and there are a number of techniques to help practitioners. Examples of several such techniques are shown in Table 4.2. However, these techniques provide only general guidelines towards finding creative solutions to problems. They lack the ability to systematically entice innovative solutions and hence may not help in identifying specific technical solutions required in industry, a limitation common to these processes.

The theory of inventive problem solving (TRIZ) is a creative problem solving methodology that has been developed by G.S. Altshuller over time (between 1946 and 1985) to help identify design solutions (Rantanen and Domb, 2002). It has been developed by observing over 14 million patents and provides guidance for creative thinking to help identify solutions (for products, processes or systems) to a given problem (Terninko et al., 1998; Savransky, 2000; Rantanen and Domb, 2002). TRIZ is being used in both manufacturing and the services sectors with a high degree of success and has shown potential in helping to instigate ideas to provide innovative solutions to problems (Shirwaiker and Okudan, 2008). It provides specific guidelines to develop unique solutions. Furthermore, minimal experience in the problem area is needed to use TRIZ to generate solutions in contrast to other brainstorming techniques. Interestingly, some of the brainstorming techniques presented in Table 4.2 (e.g. Harvey cards) also have used principles of design available in TRIZ.

Table 4.2. Techniques to aid brainstorming (Frey, 2004; Elion, 2007)

Technique	Description
Six hats (de Bono, 1985)	White- focus on data, facts and figures, information needed; Red- focus on feelings, emotions, hunches, gut instinct and intuition; Black- focus on difficulties, potential problems and why something cannot be done; Yellow- focus on values and benefits, optimistic thinking and why something may work; Green- focus on creativity, possibilities, alternatives, solutions and new ideas; Blue- focus on managing the thinking process, objectives, next steps and action plans.
EyeWire creativity cards	Contains 20 colourful cards with short brainstorming exercises to help stimulate creative muse. These exercises include proven techniques such as ‘change viewpoints’ and ‘think in opposites’.
Idea miner	A document that contains a series of thought provoking questions and exercises, to which thoughts and ideas could be added.
Pocket generator of ideas	A method for creating, inventing and generating new ideas. It has 10 prompts: reversal, division, rhythm, similarities/associations, system, resources, middleman, management, task setting and miscellaneous.
Harvey cards	A set of thought-stimulating words (e.g. animate, contradict, substitute, distort, isolate and combine).
100 whats of creativity	Contains 100 ‘what if’ questions that can serve as a powerful catalyst for the mind. Each question is followed by a short explanation and several examples of how to use it.
Jump start	State the problem or challenge; generate a list of random adjectives; form questions using these words to generate new ideas; record the underlying principle embodied in the ideas; record any other ideas sparked by these underlying principles.
Random word technique	A description of the problem, challenge or opportunity is entered into a web form. A random word is displayed on the web page. Then a second form is used to note any associations to the displayed word that come to mind. After recording a number of words or short phrases,

Technique	Description
	the associations and the problem statement are reviewed to determine whether any of the associations could be used in the problem.

However, practitioner experience is still of value to identify solutions and TRIZ may be effectively used to facilitate creative thinking in practitioners. The use of TRIZ may also help identify an increased number of possible alternative solutions (i.e. improvement of the solution space) for an identified risk or requirement. Interestingly, TRIZ also complements the QFD process (Terninko et al., 1998; León-Rovira and Aguayo, 1999; Domb, 1998). Therefore, a TRIZ-based aid to brainstorming was decided to be included in the design tool.

To help identify innovative solutions, TRIZ uses forty principles known as the 'TRIZ principles of innovation' (Terninko et al., 1998; Savransky, 2000; Rantanen and Domb, 2002), which could be used to design both products and processes. This was considered by the author to be too many to be listed in a pragmatic approach to design, for use by practitioners in the industrial setting. Thus, the list of forty principles was reviewed and some were merged based on similarities between them (as judged by the author) leading to 25 'design principles'. These were then described using non-engineering terminology (as far as possible) in order to enable a practitioner without a background in engineering to understand them easily. The formation of these design principles is described in the next paragraph:

According to Terninko et al. (1998), Savransky (2000) and Rantanen and Domb (2002), the first TRIZ principle is segmentation or fragmentation. TRIZ principles with similar meanings were searched to categorise together. Since the second TRIZ principle is described as removal/ extraction/ separation, which was also considered to be related to the first principle. Thus, these two TRIZ principles were categorised together and was given the name, 'divide and split up into elements'. After that, the categorised principles were eliminated from the list. Then, the next available TRIZ principle (i.e. the third) was observed and other principles similar to that were searched. Since TRIZ principle 6 is related to it, these two were categorised together and named 'make elements versatile' and these TRIZ principles were also eliminated from the list. This procedure was followed until all the TRIZ principles were categorised. The obtained categories are shown in Table 4.3.

Table 4.3. Design principles with corresponding TRIZ principles [within brackets, their sequential numbers as found in the literature (Terninko et al., 1998; Savransky, 2000; Rantanen and Domb, 2002)

Design principle	TRIZ principle (Principle No.)
Divide or split up into elements	Segmentation/ fragmentation (1); separation/ extraction/ removal/ taking out (2)
Make elements versatile	Local quality (3); multi-functionality/ universality (6)
Use rounded shapes and circular motion	Symmetry change/ asymmetry (4); curvature increase/ spheroidality (14)
Combine elements to make one unit	Merging/ joining/ combining/ integrating (5)
Fit one inside another	Nesting/ nested structures (7)
Reduce weight or balance weight	Weight compensation/ counterweight (8); equi-potentiality/ same level (12); porous materials (31); composite materials (40)
Take counter measures for anticipated issues	Preliminary counteraction (9); preliminary action (10); beforehand compensation (11), partial or excessive action (16); intermediary action (24)
Check reversing the order of operation	Other way around/ do it in reverse (13)
Increase adaptability to suit the conditions	Dynamic parts, dynamism, increasing flexibility (15)
Use unutilised space, change the orientation	Dimensionality change/ another dimension (17)
Use cyclic/pulsating action or ensure continuous action	Mechanical vibration (18); periodic action (19); continuity of action (20)
Skip or quickly perform the risky tasks	Hurrying/ rushing through/ skipping (21)
Make use of harmful effects	Blessing in disguise/ convert harm to benefit (22)
Use feedback signals	Feedback (23)

Design principle	TRIZ principle (Principle No.)
Make use of idling resources	Self-service (25)
Use cheap disposable copies	Copying (26); cheap disposables (27)
Replace mechanical actions with other physical actions	Mechanical interaction substitution (28)
Use the properties of gas and liquid	Pneumatics and hydraulics (29)
Use flexible and hollow structures rather than solid structures	Flexible shells & thin films (30)
Make use of physical property changes	Optical property changes/ colour change (32); parameter change/ property change (35); phase transitions (36)
Make identical material interact	Homogeneity (33)
Remove or restore used substances	Discard and recover (34)
Use expansion and contraction due to temperature change	Thermal expansion (37)
Use oxygen to help burning/ oxidising	Strong oxidants (38)
Use inert gases to prevent burning/ oxidising	Inert atmosphere (39)

Subsequently, these 25 design principles were further categorised into ‘frequently used’ (20 design principles) and ‘occasionally used’ (5 design principles) on the basis of their relevance to work-related MSDs. For example, the TRIZ principles that suggest the use of chemical properties and change of physical properties of materials were considered less likely to be used to reduce work-related MSDs, and hence, categorised as occasionally used design principles.

The design principles most frequently used were rearranged according to their usefulness to practitioners for reducing work-related risk factors for developing MSDs. The principles believed to have an influence on ‘force’ related workplace factors were highly ranked. Next, the design principles assumed to have more influence on ‘posture’ related workplace factors were listed. The TRIZ-based modified list of design principles thus formulated is shown in Appendix 4.2. These design principles were planned to be linked to the guidance material of the design tool together with the corresponding original TRIZ principles and their detailed descriptions.

The QFD-based matrix

While identifying solutions, the design information needs to be recorded. In order to facilitate this, a Microsoft® Excel template (Figure 4.2) was developed to accommodate five risks or user requirements and ten design solutions. It was based on the 'house of quality' in QFD and could be modified to accommodate more risks and requirements and solutions as necessary.

As shown in Figure 4.2, the prioritised 'risks or user requirements', and their corresponding 'observations and measurements' (e.g. force, posture and repetition etc.) are listed on the left and right columns. Identified 'solutions' for the risks and requirements are entered along with the corresponding design principle used to identify the solution in the top (horizontal) row. The 'relationship matrix' is used to enter the associations between the risks or requirements and the solutions. It is also used to list the details related to the solutions: solution type (e.g. equipment, a facility, procedures or training), resource requirement (e.g. time and material) and estimates (e.g. costs and benefits). The bottom row is to list the 'standards, guidelines and regulations' pertinent to the solutions.

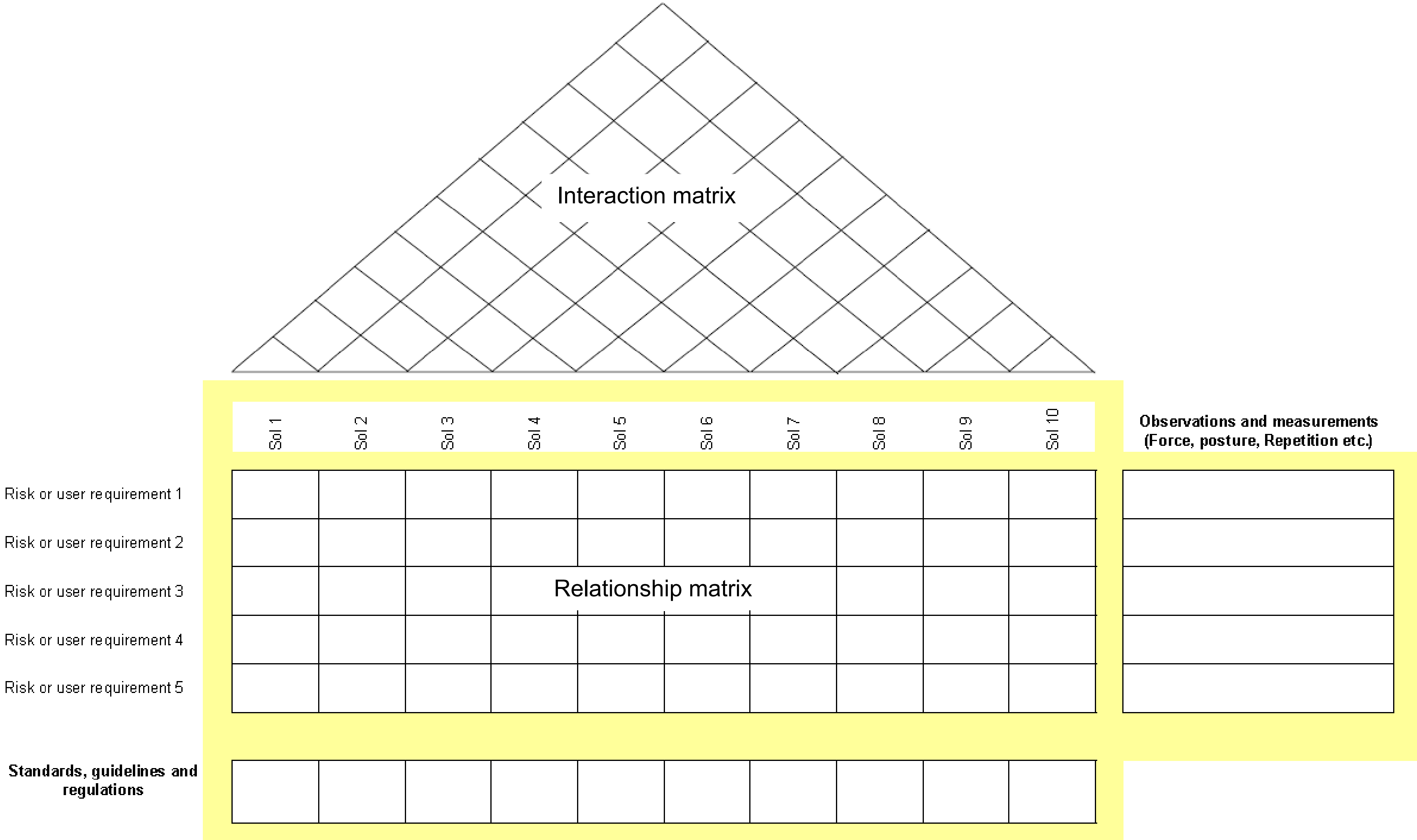


Figure 4.2. QFD template developed to enter design information

The interactions matrix represents the correlations between solutions. A “P” is placed in the corresponding cell if there is synergy (i.e. two solutions helping each other to reduce harmful effects) between two solutions. An “N” is placed if there is a negative effect (i.e. one solution contradicts with another to increase harmful effects) between the two corresponding solutions and the cell is kept blank in the case where the solutions are independent.

This simplified QFD-based matrix format can be explained using the example shown in Figure 4.3. The columns on the left and the right are to list the user requirements and the corresponding observations. S_1 to S_7 shows the solutions identified to address the requirements. R_1 to R_8 represent the relationships between the requirements and the solutions. For example, R_6 is the relationship between Requirement 3 and S_5. SGR_1 to SGR_7 are the standards, guidelines and regulations corresponding to S_1 to S_7. The triangular matrix is used to visualise the interactions between the solutions. For example, $I_{2,\,5}$ represents the interaction between S_2 and S_5. It can be a positive (P), negative (N) or ‘no interaction’ depending on the correlation between the two solutions.

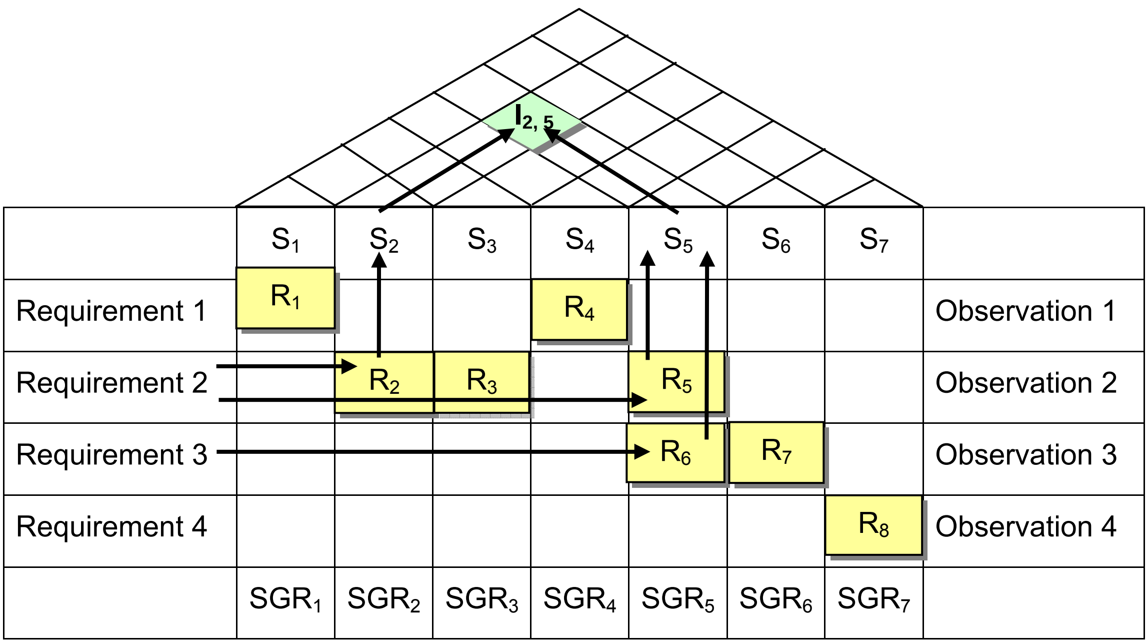


Figure 4.3. Schematic representation of the simplified QFD house of quality matrix to present design information to reduce work-related MSDs

4.5.4. Selecting acceptable solutions

After the design information is entered, technically infeasible solutions need to be identified. Then, those that may potentially introduce new workplace risks need to be distinguished from the listed solutions. Although a QFD house of quality matrix can be conveniently used to visualise design information (Terninko et al., 1998), it needs to be modified to help select acceptable solutions. It has already been discussed that attributes of axiomatic design can be used to enhance the performance of the QFD process (Helander and Lin, 2002; Gonçalves-Coelho et al., 2005; Chai et al., 2005). Two important concepts of axiomatic design (Suh, 1990); namely, information and independence axioms can be used in conjunction with QFD in order to help identify infeasible solutions. Those solutions that may potentially introduce new workplace risks can also be noted by finding interactions between different solutions. The guidance material in the design tool will provide instructions to colour code the solutions in the QFD-based matrix (using the Microsoft® Excel 'cell colour' toolbar) to aid visualisation. This process is illustrated in the flow chart in Figure 4.4.

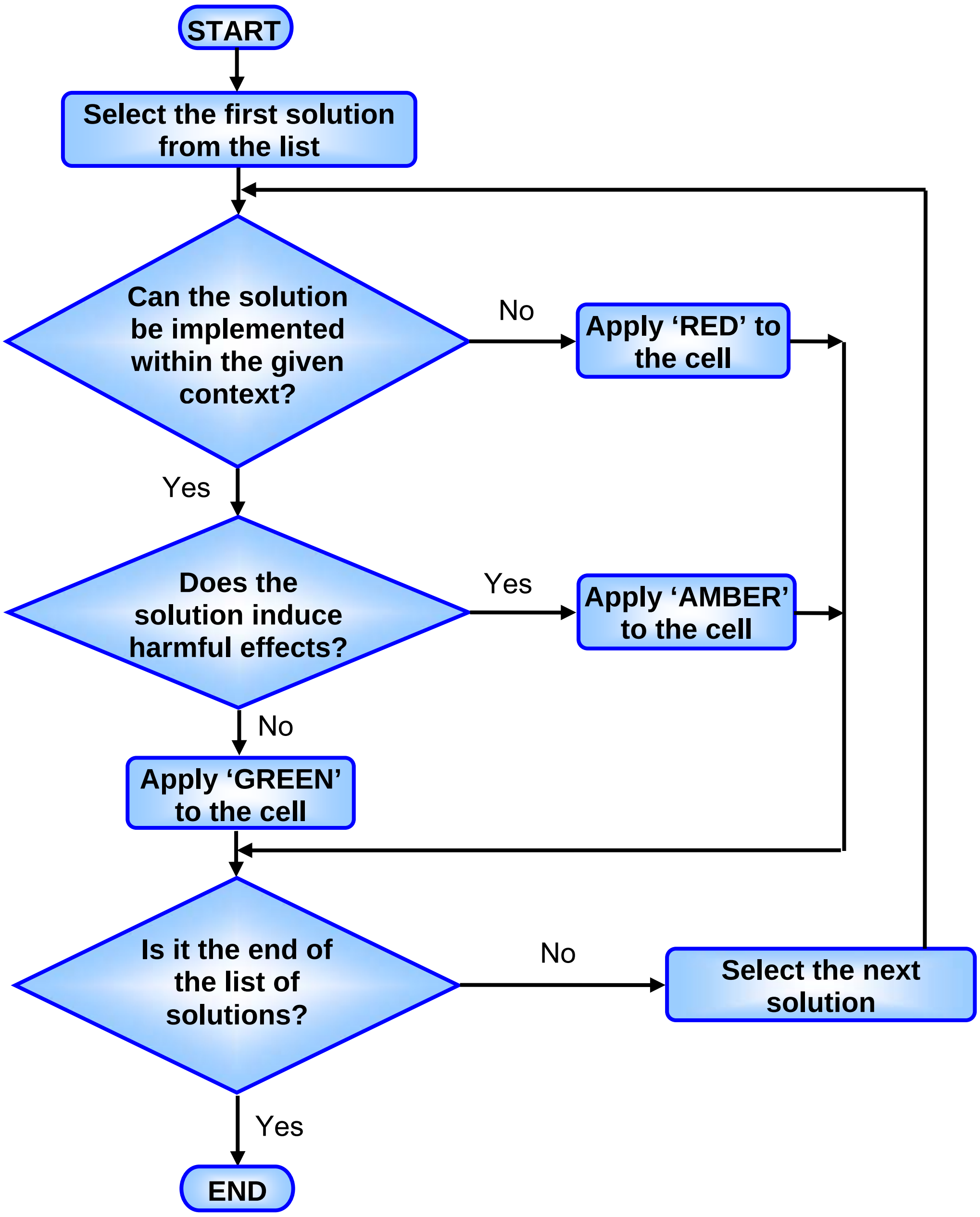


Figure 4.4. The process of selecting acceptable solutions

4.5.5. Presentation of risks and user requirements, and solutions

After determining the solutions to address the requirements for design, information needs to be managed and presented in a format that is easy for the practitioners and the other stakeholders such as the users (workers) and managers to comprehend. Effective presentation would help bridge the gap between the users and the practitioners of design. Methods to communicate top level design information with regard to all design aspects (i.e. equipment, facilities, procedures and training) need to be investigated. Those adopted in linear and concurrent engineering such as QFD and axiomatic design may be helpful in fulfilling this need. These methods were discussed in detail in Section 2.7 and Section 4.2, and QFD matrices (house of quality) were shown to have potential in facilitating the stakeholders to visualise the design information and help them select acceptable solutions to carry forward in the design process for implementation.

An investigation of the literature on design information required by stakeholders in the design process indicates that the following information is useful for effective design.

- Prioritised risks and user requirements: The literature on QFD stresses the importance of knowing the user requirements and relating them to the solutions. In addition, the importance of obtaining user requirements from the users themselves to ensure conformity of the design to the requirements is emphasised (e.g. Akao, 1990). The ability to track these user requirements pertinent to any of the design attributes is an important aspect in this regard.
- Observations data relevant to the risks and user requirements: In addition to the user identified risks and requirements, practitioners can include detailed information to supplement the process of identifying design solutions. This includes information such as measurements, risk assessment data and practitioner notes. Observational data would also help determine parameters for detailed design.
- Solutions identified to address the risks and user requirements: Practitioners need to be able to visualise the solutions identified. This will enable the selection of appropriate solutions by comparing and contrasting the total solution space. Finally, once the reduction phase, where the infeasible solutions are eliminated from the total solution space, practitioners will be able to visualise the feasible set of solutions that should be carried forward to the next stage of the design process.
- Relationships between risks and user requirements and the corresponding solutions: Enabling the stakeholders to visualise the links between the identified risks and requirements and the relevant solutions is vital. This would ensure that none of the risks or requirements identified is neglected in the design process, the importance of which is evident in literature. Information such as type of solution, cost, benefit and time considerations for implementation should also be known in order to establish the relationships and facilitate comparison of solutions.

- Standards, guidelines and regulations: These are available to support practitioners in identifying solutions. They specify the limits within which the solutions have to be decided and should be taken into account when developing solutions. As a result, this information becomes imperative to determine the parameters of detailed design.
- Interactions between solutions: The independence axiom in axiomatic design (Suh, 1990) specifically states that in order for a design to be successful, there should not be interactions between any two design parameters, or at least, the interactions need to be predictable. If there are interactions, they are known as coupled designs, which give rise to dependencies among design parameters. As a result, it is important to visualise such interactions.

It was identified in the literature that a simplified QFD house of quality matrix would ensure effective presentation of design information and help communication among stakeholders in the design process. In the original QFD house of quality matrices, design information such as competitor user requirement analysis, competitor technical requirement analysis and technical targets are presented using mathematical relationships (Akao, 1990; Day, 1993). However, this information may be omitted from the proposed design tool as mathematical relationships may hinder effective visualisation of design information by all stakeholders in the design process. In addition, the necessity to present such data in a tool to enhance communication may not arise. Stakeholders potentially involved in design decisions to reduce work-related MSDs include users and practitioners such as ergonomists and engineers that possess varied educational backgrounds (especially technical and mathematics). Therefore, inclusion of mathematical operations in a tool to enhance communication is debatable. In addition, it may be difficult to integrate mathematical operations in the initial design stage. Furthermore, if the original form of QFD is used, it will result in an explosion of data, which would be difficult to manage as discussed by Appleton and Short (2007). As a result, relationships based on mathematical operations were omitted from the design tool. For the same reasons, information based on competitor analysis was also omitted from the tool. A very important feature of the QFD-based matrix is the ability to change its format to suit the application allowing the possibility to add, omit or change the matrix according to the need. Therefore, the QFD-based matrix template shown in Figure 4.2 was used in the design tool without change to visualise the required design information in a single interface to provide guidance in reducing work-related MSDs.

4.5.6. Recording knowledge in a solutions database for future use

It is beneficial to record design information for use in future applications as the solutions identified for one problem may be used to solve another in a different context in a structured manner. For example, Eder (2001) describes that information from previous projects can be used to decide which portion of the system needs to be redesigned and which needs little or no alteration. In addition, the design information emanating from previous projects can be used to facilitate continuous improvement of work systems. Doultsinou et al. (2009) describe the importance of using information from previous projects in a study on developing a service knowledge reuse framework for engineering design. Although effective knowledge management is desirable, researchers have identified that integrated systems are rare due to the diversity of stakeholders with individual knowledge about projects, products and processes (Ebert and de Man, 2007). However, database systems are frequently used to store data on projects, products and processes, and to improve collaboration among stakeholders of design (e.g. Shai and Reich, 2004; Ebert and de Man, 2007). Thus, a database was thought to be beneficial to store the design information gathered from projects. It would store the information that is presented in the proposed QFD-based matrix. Retrieved design knowledge acquired from previous projects could be used along with design principles to identify solutions in future projects to effectively minimise work-related MSDs.

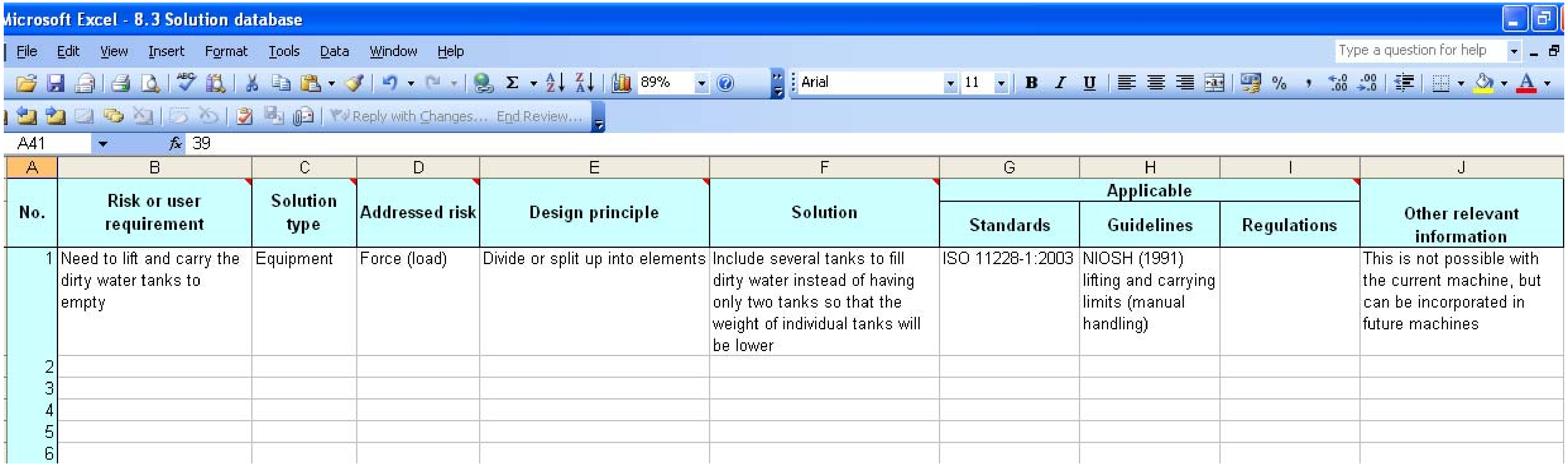
The development of the solutions database

The structure of the 'solutions database' is shown in Table 4.4. The database was developed using Microsoft® Excel to facilitate change or addition of fields as necessary with ease. One record was added to the database as a guide to help comprehend the design information that could be stored in it (Figure 4.5).

Table 4.4. Fields of the solutions database

No.	Field	Description
1	No.	Index number for the records
2	Risks or user requirements	Identified risk or requirement
3	Solution type	Drop-down list to select whether the solution is for equipment, facility, procedure, training or other.
4	Addressed risk	Drop-down list to select the work-related MSD risk:

No.	Field	Description
		force (load), posture, repetition or other
5	Design principle	Drop-down list to select design principles
6	Solution	Description of the design solution
7	Applicable standards/ guidelines/regulations	Standards, guidelines and regulations used in the development of the design solution
8	Other relevant information	Other information that may be of importance such as project context, cost, benefit and references.



No.	Risk or user requirement	Solution type	Addressed risk	Design principle	Solution	Applicable Standards	Applicable Guidelines	Applicable Regulations	Other relevant information
1	Need to lift and carry the dirty water tanks to empty	Equipment	Force (load)	Divide or split up into elements	Include several tanks to fill dirty water instead of having only two tanks so that the weight of individual tanks will be lower	ISO 11228-1:2003	NIOSH (1991) lifting and carrying limits (manual handling)		This is not possible with the current machine, but can be incorporated in future machines
2									
3									
4									
5									
6									

Figure 4.5. Solutions database

4.6. Presentation of the design tool (and guidance material)

The design tool based on quality function deployment (QFD) was developed for practitioners to help identify risks and obtain user requirements and provide acceptable solutions to reduce work-related MSDs among workers in industry. It focused on improving equipment and processes in the industry to suit workers. The features and the guidance material for the proposed design tool summarised in Figure 4.1 are as follows (underlined were the methods and tools linked to the guidance material):

1. Identifying risks and obtaining user requirements

Useful methods	Guidance/examples
Questionnaires User-interviews Focus groups	Encourage workers to reflect on the work tasks and MSD risks. Interview guide to identify MSD risks and obtain user requirements.
Observations (e.g. Task analysis, note taking, RULA, REBA, QEC)	Note down observations. Focus on musculoskeletal loading (forces), posture, and repetitions (cycle time). Example Observations proforma. REBA assessment. Example REBA proforma. Measure and/ or estimate musculoskeletal loading (force), posture and repetition etc., where possible. (loading (e.g. forces), posture (e.g. REBA scores), and repetitions (e.g. cycle time) etc.) Video recordings, photographs will aid the analysis.
Checklists	e.g. ILO and IEA.1996. Ergonomic checkpoints: Practical and easy-to-implement solutions for improving safety, health and working conditions. International Labour Office & International Ergonomics Association.
Standards and guidelines	e.g. Karwowski, W. 2006. Handbook of Standards and Guidelines in Ergonomics and Human Factors. Taylor and Francis. HSE. 2003. Manual handling assessment chart (MAC) tool. DSTAN. 2009. UK defence standardisation. NIOSH. 2007. Ergonomic guidelines for manual material handling.

Useful methods	Guidance/examples
Discomfort analysis	Whole body discomfort (WBD) map. Example WBD map.
Experience-based judgements	Expert evaluation of work.

2. Prioritising the risks and user requirements

Useful methods	Guidance/examples
Content analysis	Extract themes from methods used to obtain user identified risks and requirements. Prioritise (e.g. use the tool based on constant comparative method and frequency analysis). Reference: Glaser, B.G. and Strauss, A.L. 1967. The discovery of grounded theory. Aldine de Gruyter, New York. Add detail to the identified risks and obtained requirements using observation data.
Other techniques	e.g. Saaty, T.L. 1980. The Analytic Hierarchy Process: Planning, setting priorities, resource allocation, McGraw Hill, New York.
Experience-based judgements	

3. Identifying design solutions

Useful methods	Guidance/examples
QFD	Refer to the QFD matrix. List all the risks or user requirements on the left column of the matrix in order of priority.

Useful methods	Guidance/examples
	List the corresponding observations (e.g. measurements and/ or estimates, of loading (e.g. forces), posture (e.g. REBA scores), and repetitions (e.g. cycle time) etc.) in the right column of the matrix. Select one of the risks or user requirements from the list. Refer to the list of design principles to aid thinking. Select appropriate design principles (e.g. divide or split up into elements) that may eliminate harmful effects (e.g. force, posture and repetition). Corresponding TRIZ principles and descriptions are also listed to help further clarify the design principles. Suggest solutions (e.g. for equipment, facilities, procedures and training) using the selected design principles for guidance. List the solutions in the top row of the matrix. In the "relationship matrix", note the relationship between each risk or user requirement and the solutions (e.g. whether the solution is for equipment, facilities, procedures or training). Also note other relevant information such as resource requirement. Note any corresponding standards, guidelines and regulations against the solutions in the last row. Repeat for all risks and user requirements. In the triangular matrix (i.e. interactions matrix), mark effects (**P-** positive effect. i.e. two solutions helping each other to reduce harmful effects); **N-** negative effect. i.e. one solution contradicts with another to increase harmful effects) among solutions. Use the solutions database whenever possible to help identify solutions.

4. Selecting acceptable solutions

Useful methods	Guidance/examples
Features of TRIZ and axiomatic design	Note the solutions that are technically infeasible. Mark the corresponding cells in **RED**. Try to modify these solutions to make them feasible (i.e. **AMBER** or **GREEN**). Note solutions that are technically feasible but induce harmful effects. Mark the corresponding cells in **AMBER**. Try to modify these solutions to eliminate negative effects (i.e. **GREEN**). Note the solutions that a) are feasible and b) do not induce harmful effects. Mark the corresponding cells in **GREEN**.

5. Presentation of risks and user requirements, and solutions

Useful methods	Guidance/examples
QFD	Refer to the QFD matrix. Use it to present the risks, requirements with related observations and, proposed solutions with related standards, guidelines and regulations. When selecting solutions to provide solutions to the MSD problems, use the priority order **GREEN**, **AMBER** and **RED**. Give priority to the solutions that use available and cheap resources. In the triangular matrix (interactions matrix), mark effects (**P-** positive effect. i.e. two solutions helping each other to reduce harmful effects); **N-** negative effect. i.e. one solution contradicts with another to increase harmful effects) among solutions.

6. Recording knowledge in a solutions database for future use

Useful methods	Guidance/examples
Recording solutions	Refer to the solutions database. Record important information to the solutions database to use in future applications.

4.7. Summary

Facilitating communication among the stakeholders in the design process is one avenue of improving the effectiveness of approaches to design. For this, appropriate tools and techniques are needed. By reviewing the relevant literature, a design tool (and guidance material) was developed in order to enhance communication in the design process. QFD was found to be an effective method to manage and integrate design activities and present design information. As a result, QFD was used as a basis to develop the design tool supplemented by methods and tools to manage and visualise design information, and to guide practitioners such as designers, engineers and ergonomists in the design process.

5. Practitioner survey

5.1. Introduction

The development of the design tool (and guidance material) was presented in Chapter 4. In order for it to be useful for the potential users as an effective and efficient approach to reducing work-related musculoskeletal disorders (MSDs), its feasibility must be understood. The choice of strategy to assess the design tool is an important decision. Rosenbaum (1989) suggests usability evaluation. A three pronged strategy was adopted to assess the design tool adapting techniques from a list presented by Pace (2003) for the assessment of products. The assessment strategy first included a survey, which is described in this chapter. Then, in-depth interviews (refer Chapter 6) and case studies (refer Chapter 7) were conducted to evaluate the feasibility, usability, and strengths and weaknesses of the design tool in the field setting. The practitioner survey was conducted to obtain general feedback on the quality function deployment (QFD)-based design tool (and its guidance material) in order to evaluate its feasibility with respect to current practice (refer Chapter 1: Objective 3). The sub-objectives of the study were:

- To explore the potential of the design tool in the field setting;
- To evaluate the elements of the design approach against practitioner requirements;
- To identify practitioners for the in-depth interviews and case studies.

In order to address these objectives, details of the practitioners' expertise and their involvement in reducing work-related MSDs needed to be gathered. In addition, information about the tools and techniques that they frequently used and their views on the performance of these in the industrial environment were necessary. Furthermore, the requirements of these practitioners in terms of tools and techniques to help them reduce work-related MSDs needed to be elicited. The process should include as many relevant practitioners as possible in order to help generalise the findings and to facilitate the subsequent studies that were planned. Thus, the best strategy for this study was identified as an online questionnaire survey. A discussion of sampling, data collection, analysis and results of the practitioner survey follows.

5.2. Sampling

It was decided to focus on practitioners involved in ergonomics and design to reduce work-related MSDs. The 57 registered consultancies listed in the database of the Ergonomics Society, UK (renamed as the Institute of Ergonomics and Human Factors) were contacted in December 2008. This database representing 144 ergonomists was specifically chosen as it is the professional body of the ergonomics community in the UK, and many relevant practitioners are affiliated to it.

A standard email (Appendix 5.1) was sent to all (61) contact email addresses listed in the database inviting them to participate in the survey. They were requested to forward the email to any of their colleagues that might be interested in taking part in the questionnaire survey. The 61 listed contact persons were sent the email irrespective of the fact that some of the consultancies might not be involved in the area of work-related MSDs. A follow-up email was then sent three weeks after the initial email in order to increase the response rate. In addition, a notice (Appendix 5.2) requesting participation in the study was published in the Ergonomics Society's monthly newsletter, "The Ergonomist - January 2009 edition". This newsletter is distributed among 1400 organisations and individuals (personal communication with the editor) and was expected to reach a wider group of organisations and individuals.

The introductory page of the questionnaire provided the participant with information according to the university ethical guidelines for studies involving human participants (Loughborough University, 2003). The optional requests for a copy of the design tool and/or the summary of findings were included as an incentive for the practitioners and to attract interest for the subsequent studies (interviews and case studies).

5.3. Data collection

A paper based questionnaire was initially developed and piloted with work colleagues (n= 4). They were asked to comment on the clarity of content, the flow of questions, and appropriate changes were then made according to their suggestions, for example, the category of 'health and safety practitioner' was added to the list of occupations. In addition, numbered lists in open ended questions were removed. The questionnaire was hosted using an online questionnaire survey tool (www.surveymonkey.com). This was again piloted with work colleagues (n= 3). They were specifically asked to proof read the questionnaire and comment on the functionality of check boxes, option buttons and text boxes used to record information. No amendments were necessary. The expected time to complete the questionnaire was 5-10 minutes.

The link generated by the survey tool was attached to the email requests that were sent to the practitioners so that they could easily access the questionnaire. For convenience, the link was shortened using another tool (www.tinyurl.com) when the notice for the study was published in the Ergonomics Society's newsletter. Appendix 5.3 shows the questionnaire prepared (Microsoft® Word format) to help generate the online survey. The main sections of the questionnaire are summarised in Table 5.1.

Table 5.1. Summary of the questionnaire

Section	Elicited information
Introduction	Brief about the research and the objectives of the survey; researcher contact details
Personal and job information	Gender, company name, current occupation, job responsibilities, experience and expertise as a practitioner
Participatory methods to help reduce work-related MSDs	Information on methods being used to assess MSD risk; identify user requirements to reduce work-related MSDs; prioritise user requirements; develop specific design solutions; help innovation and views on formal or informal participatory processes used
	Ratings for the performance of methods/tools currently being used with regard to the elements of the proposed design tool such as identifying MSD risks and obtaining user requirements (using a scale 1= very poor to 7= excellent)
The participatory design tool to help reduce work-related MSDs	Importance of an integrated tool to help the process involved in designing/improving (using a scale 1= not important to 7= highly important)
	Rating of importance of elements of the proposed design tool, for example, identify design solutions and ability to present user requirements/design solutions (using a scale 1= not important to 7= highly important); additional elements required
Further research	Interest in participation in an interview and try out the design tool; receiving a copy of the design tool; receiving a summary of the findings of the questionnaire; if interested, contact details

5.4. Analysis

Descriptive analysis of gender distribution, occupational group, job responsibilities, levels of experience and expertise was conducted. Relevant frequency distributions were then graphically presented to understand the characteristics of the sample of practitioners. Responses to the open ended questions were also considered when determining the frequency distributions.

Participatory methods currently being used by the practitioners to help reduce work-related MSDs were analysed. Descriptive analysis of methods to assess risks for developing work-related MSDs; identify user requirements to reduce work-related MSDs; prioritise user requirements and to develop specific design solutions was performed, and the results were graphically presented. Methods to help innovate and details of participatory processes the practitioners use were extracted from the data and were listed. The constant comparative method (Glaser, 1965; Erlandson et al., 1993; Boeije, 2002) was used to identify and define themes. Then content analysis was used to count frequency to prioritise the themes according to frequency of occurrence.

Performance ratings for the methods used by practitioners with regard to identifying MSD risks; obtaining user requirements; prioritising these requirements; identifying design solutions to address these requirements; ability to present user requirements/ design solutions; checking feasibility of any solutions; integration of the above elements, and the ability to record knowledge for improvements/future applications were summarised by calculating frequencies (% practitioners) against the ratings (1 to 7) and were graphically represented. The mean and standard deviation (SD) of the ratings for each element were calculated from frequency data.

A similar procedure was used to analyse the importance of ‘an integrated tool to help the process involved in designing/improving equipment and reducing work-related MSDs’. The reasons for these ratings were extracted from the entries to the open ended question. Similar themes were categorised together once again using the constant comparative method. A similar analysis was also performed for the importance ratings for the individual elements of the design tool. Additional practitioner requirements were extracted from the entries to the open ended questions by identifying themes as described by Meyer and Avery (2008). Again frequency ranking was used to prioritise the themes. Finally, a list of participants willing to take part in subsequent studies to be interviewed and try out the tool was identified.

5.5. Results

5.5.1. Participants

Data were collected from the 20th January 2009 - 20th August 2009. As mentioned earlier, the 57 consultancies had 144 registered ergonomists. Of these, 124 successfully received the email. In all, 32 practitioners responded to the questionnaire. However, only 23 (72% of the respondents) completed the entire questionnaire: the others missed certain sections. 21 out of the 32 respondents were from the Ergonomics Society registered consultancies and represented 21% (12 out of 57) of the registered consultancies that were contacted.

5.5.2. Personal and job information

Out of the 32 practitioners who responded to the questionnaire, there were 19 males (59%) and 13 females (41%). Figure 5.1 shows the distribution of respondents according to their occupation. A high percentage of respondents (66%) identified themselves as ergonomists and 33% of them were consultants. 57% of the practitioners that identified themselves as lecturers also reported other occupation categories. All of the health and safety practitioners also identified themselves as ergonomists. Respondents that distinguished themselves as human factors engineers (6%) were different from the respondents that identified themselves as engineers (6%). The respondents that specified their occupation as 'other' included two researchers, an osteopath and an occupational health technician.

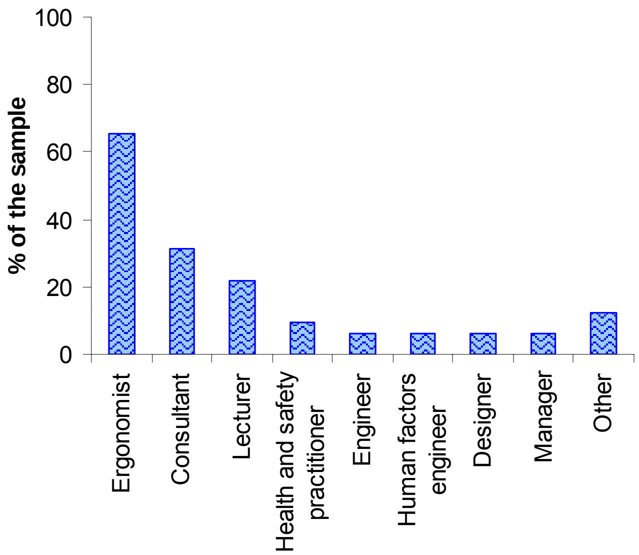


Figure 5.1. Current occupation of respondents (n = 32)

The results indicated that the practitioners hold a variety of job responsibilities with a high proportion (81%) saying that they manage ergonomics projects. User needs analysis, equipment and task design, conducting user trials, MSD risk assessment and user measurement assessment were recognised as job responsibilities by 69%, 62%, 62%, 59% and 41% of the practitioners respectively. Other responsibilities indicated by

28% of the respondents included researching, heuristic evaluation of artefacts, teaching, simulation using human modelling, training, evaluation of artefacts, health surveillance, method study and customer engagement. Only 16% of the practitioners reported less than two job responsibilities. 22% of the practitioners reported job responsibilities in all listed job areas. Respondents in general possessed a considerable number of years experience as practitioners (Table 5.2), where the majority (65%) of respondents had more than 10 years of experience.

Table 5.2. Experience as a practitioner (n = 32)

Experience (years)	% respondents
0 - 5	4
6 - 10	31
11 - 20	31
≥ 21	34

The majority of the respondents reported expertise in relation to a wide range of areas related to MSDs and design (Figure 5.2). Practitioners indicated expertise in multiple areas, often selecting three or more areas.

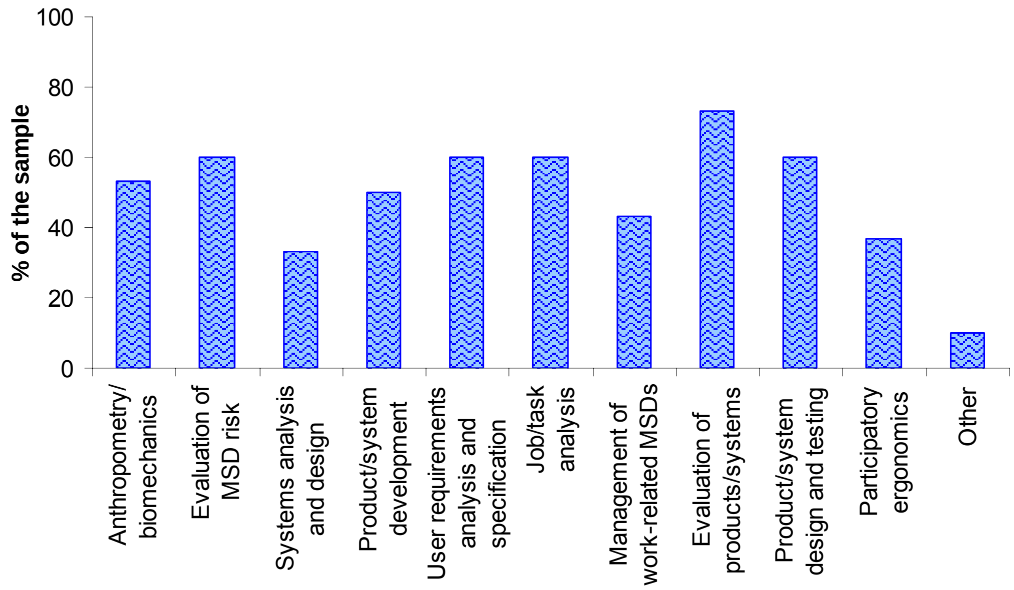


Figure 5.2. Areas of expertise of the respondents (n = 30)

5.5.3. Participatory methods to help reduce work-related MSDs

The majority of the respondents (75%) completed the section on MSD risk assessment methods: rapid upper limb assessment- RULA (79%) and body discomfort scales (79%) were the most commonly used methods. In addition, rapid entire body assessment- REBA (50%), quick exposure check- QEC (21%) and Ovako working posture analysis system- OWAS (21%) were also used by practitioners. Posture, activity, tools and handling- PATH was not used by any of these respondents. 91% used more than one method to assess MSD risk, and the remainder reported only either REBA or body discomfort scales as methods used to assess MSD risk. Other methods mentioned included OCRA, National Institute of Occupational Safety and Health (NIOSH) lifting equation, psychosocial tables, the Borg scale, strain index, University of Michigan 3-D static strength prediction model, mannequin®, electromyography (EMG), heart rate, dynamic postural vibration, heat stress analyses, contact pressure mapping, Institute of Occupational Safety and Health (IOSH) risk assessment methodology, expert evaluation, observation and accident reports. Two of the respondents indicated that they use proprietary methods for risk assessment, but did not reveal them.

Out of the 23 respondents that completed the entire questionnaire, user-interviews (96%), observation techniques (91%), questionnaires (78%) experience-based judgements (70%) and checklists (65%) were the most popular methods among practitioners to identify user requirements. Focus groups were less popular (39%) among the practitioners compared with the other methods. Data also indicated that the practitioners do not depend on a single method, but use a combination of methods to identify user requirements. Other methods included proprietary tools, quality function deployment (QFD) and task and job analysis, but no details were given.

39% of the respondents stated that they use formal method(s)/tool(s) to help prioritise the user requirements that they identify in order to reduce work-related MSDs. Results from risk assessment, QFD, task and job analysis and proprietary tools were used by the respondents to prioritise the user requirements. However, details on the methods they use were not given.

Out of the 23 respondents that completed the entire questionnaire, ergonomics guidelines (96%), Experience-based judgements (78%), studying similar cases (65%), and innovation (43%) were used to develop design solutions. Altogether 87% of the respondents indicated that they relied on more than one method to develop design solutions. Practitioners also use other methods: ergonomics standards, laboratory and field based testing of product performance, proprietary design guidelines developed over time, validation testing to assess and refine design solutions, human modelling, user consultations and evaluating the evidence base.

90% of the respondents that use innovation techniques to develop solutions provided insights on the methods they use. These were:

- Looking for gaps in current practice or the state of the art
- Looking at the availability of new technology that may be applied to an old product or a market opportunity that is not being met (new product opportunities)
- Using ergonomics guidelines, experience-based judgements, looking at similar cases
- Combining old designs and ergonomics skill sets to support the design process
- Brainstorming or development of new ideas
- Information from suppliers and trade shows and proprietary tools.

Furthermore, 65% of the practitioners responded positively to the question concerning the use of formal or informal participatory processes in design to reduce workplace risks for developing work-related MSDs. These are listed as follows:

- Working with small groups of users; user workshops, user participation in project steering groups; discussions with user's, stakeholders and management; system groups; focus groups; interviews; informal participant drawings; modelling in group setting; and user trials (n= 9)
- Iterative processes for product design and validation; defining the hypothesis, discussing and validating with users, defining the final project, try again and give final validation (n= 2)
- Workers work together and come up with solutions. If they are simple solutions, they will be implemented immediately (with the help of engineers). If they require more time and resources, they will be put onto an action plan to be completed within the following 6 months (n= 1)
- Failure mode and effects analysis (FMEA) (n= 1)

5.5.4. Performance of participatory methods currently being used

The practitioners rated the performance of participatory methods/tools currently being used, on a 7 point scale (1= very poor to 7= excellent) with regard to the elements of the proposed design tool and are graphically represented in Figure 5.3.

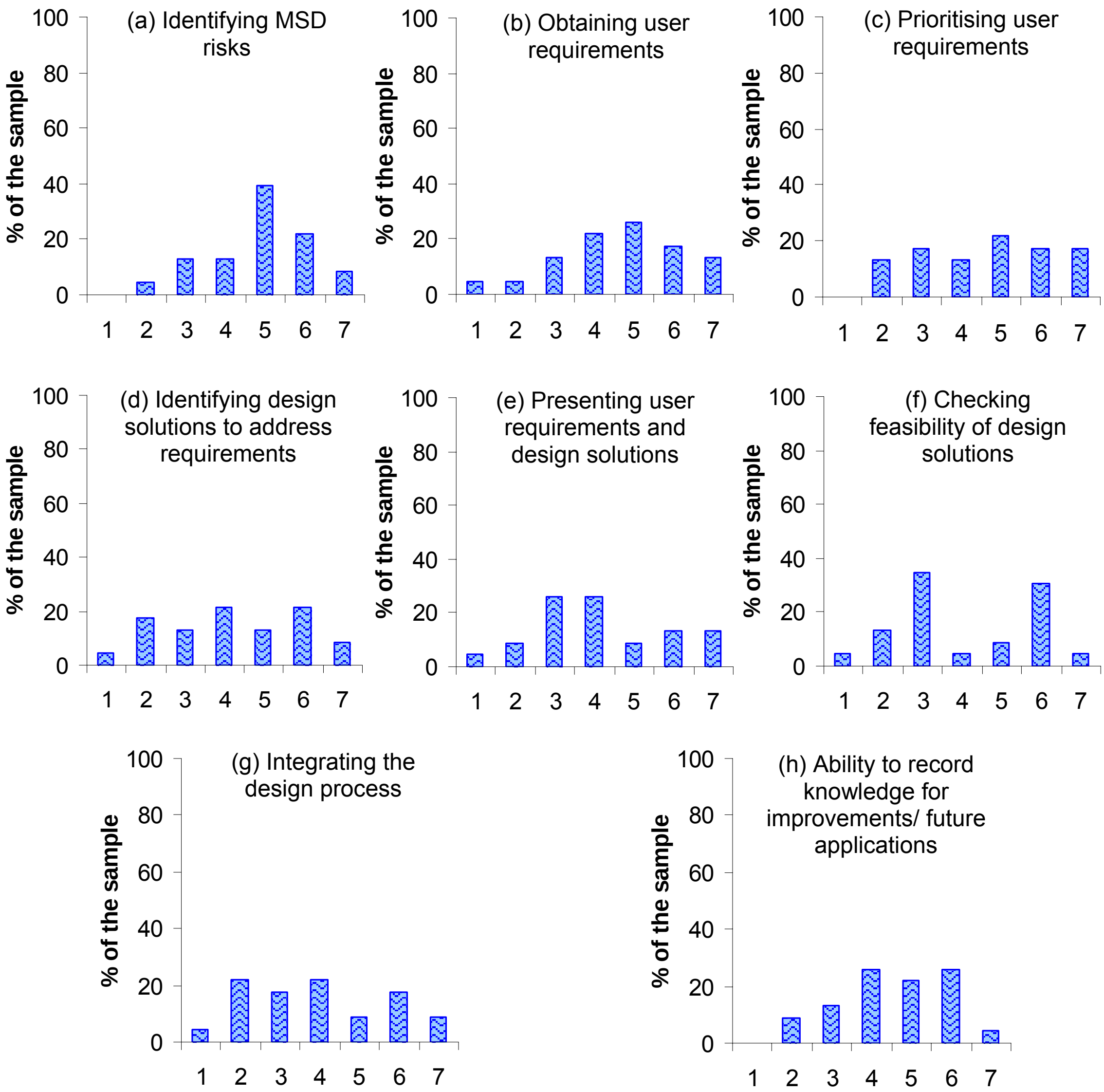


Figure 5.3. Ratings for performance of participatory methods/tools being used by the practitioners (n = 23)

Practitioners were generally satisfied with the participatory methods currently being used to 'identify MSD risks' and 'record knowledge for improvements/future applications' where the ratings ranged from 2 to 7 with a mean rating of 5 (SD 1). The majority of the participants rated the performance greater than 4 (≥ 5). The distribution of performance ratings of methods used for 'checking feasibility of design solutions' had a mean of 4 (SD 2), but clearly showed two separate clusters of responses (bi-modal) indicating that the practitioner opinion was divided on the performance of related methods. The ratings for performance of participatory methods being used for ‘obtaining user requirements’, ‘prioritising user requirements’, ‘identifying design solutions’, ‘presenting user requirements and design solutions’ and ‘integrating the above elements’ showed mixed responses. For methods for ‘obtaining user requirements’ and ‘prioritising user requirements’, the mean ratings were 5 (SD 2) and the majority rated the performance greater than 4 (≥ 5). For ‘identifying design solutions’, ‘presenting user requirements and design solutions’ and ‘integrating the above elements’ the mean ratings were 4 (SD 2) and the majority of the practitioners rated the performance less than 5 (≤ 4).

5.5.5. Importance of elements of the design tool

A high importance (mean rating= 5: SD 1) was given to having an integrated tool to help the process involved in designing/improving and reducing work-related MSDs. Out of 23 practitioners, 69% rated this aspect of the tool greater than four (≥ 5). This need was reflected in the practitioners’ comments. For example:

> *Will help ‘put things together’ in some coherent way. Right now, different tools have to be used for the assessments and sometimes some of the data that is collected is wasted as it cannot be put in a coherent way.*
>
> Respondent 19: Practitioner survey

Five respondents also identified possible benefits that an integrated design process could offer the practitioners. These were, avoiding sub optimisation; making it possible to manage different tools for risk estimation and problem solving; a reduction in the time required to carryout projects; help to cover broader aspects of work and making it possible to validate the solutions. Comments of two of the practitioners are quoted:

> *Product and equipment design requires the involvement of many specialists within businesses each with their own agenda. Consistency and standardisation are important to validate and express the importance of current and future requirements.*
>
> Respondent 12: Practitioner survey

Generally, this work is consultancy based, which means time pressure to produce solutions. A tool that could identify risk of MSD and focus future change seems highly beneficial.

Respondent 14: Practitioner survey

Two respondents recognised the benefits the tool could offer workers that are exposed to workplace risk factors for MSDs, and commented that it would be possible to improve worker knowledge, worker satisfaction and sickness records through the reduction of risk.

Integrating all elements can improve workers knowledge of the risk of MSDs and by designing and improving equipment to reduce the risk of MSD development can improve work satisfaction and allowing workers to have a more comfortable working environment and reduce time off work.

Respondent 31: Practitioner survey

Establishing any problems and implementing the solutions is crucial. This could be used in the designing and improving of equipment, which would have a positive effect on reducing MSDs within the workforce. This also would have an effect on improving sickness records etc.

Respondent 32: Practitioner survey

However, three of the respondents were sceptical about an integrated approach and expressed reservations, and commented on possible drawbacks. Examples drawn from the responses are quoted:

Difficult to comment without seeing it, but could be restrictive if too formulaic and [we] *seem to do fine without one.*

Respondent 05: Practitioner survey

Not sure how an integrated tool would work. Worried about missing stuff or about reducing the input of the 'expert' or the 'users'.

Respondent 06: Practitioner survey

Two of the practitioners commented that, for them, the importance of an integrated approach for design was low as they already had ample experience to integrate information and tools for integration.

> *Our business has two distinct components. These are product testing and design, and workplace ergonomics. Our work is extremely diverse as are our customers. While there are similarities that may benefit from an integrated tool, there are too many completely unrelated aspects. For us, the integrated tool is our computer system and our method is filing projects and knowledge.*
>
> Respondent 20: Practitioner survey

Figure 5.4 graphically represents the importance ratings for the elements of the proposed design tool given on a 7 point scale (1= not important to 7= highly important). Practitioners consider ‘identifying MSD risks’, ‘obtaining user requirements’, ‘prioritising user requirements’, ‘checking feasibility of design solutions’, ‘integrating the design process’ and ‘recording of knowledge for improvements/future applications’ to be highly important for a participatory design tool where 65-78 % of the practitioners had rated them either 6 or 7 (mean rating= 6: SD 1). Although the mean rating was 5 (SD 1), ‘identifying design solutions’ and ‘presenting user requirements and design solutions’ showed less importance compared to the rest of the elements of the design tool. However, 74% and 78% of the practitioners rated the importance of these two elements greater than 4 (≥5).

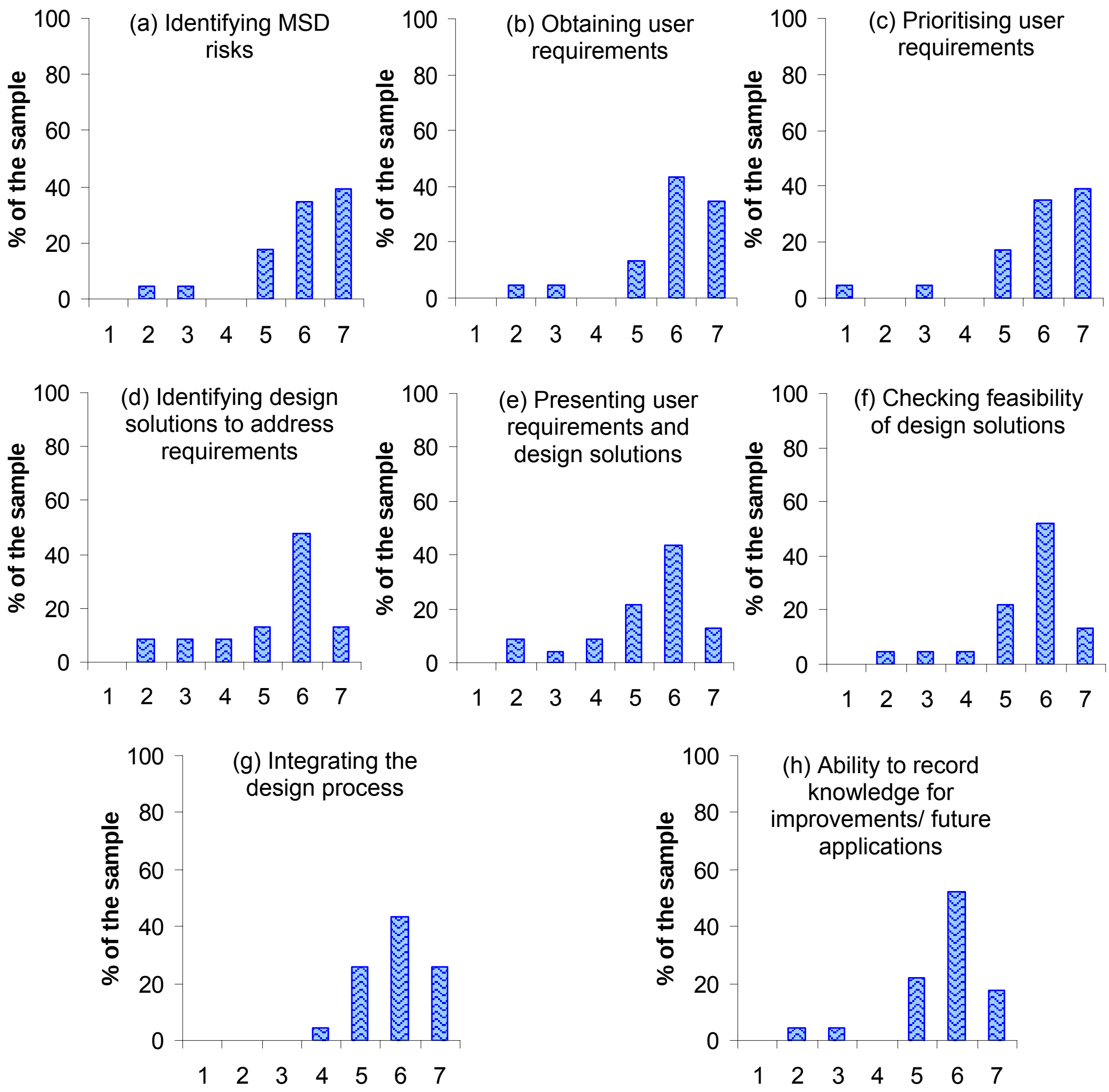


Figure 5.4. Ratings for importance of elements of the proposed design tool (n = 23)

Eleven of the 23 practitioners answered the open ended question asking them to comment on additional elements that they thought would be required to make the design tool more comprehensive. These are listed as follows (with the number of practitioners within brackets):

- Record the rationale behind the user requirements. i.e. why were they specified?; transparency as to what each of the requirements was based on, either standards or basic ergonomic principles (n= 2)
- Ability to prioritize information and to help the designers identify the most appropriate course of action when they had created some concepts (n= 2)
- Ability to share information effectively with cross-functional teams (n= 1)

- Ensure that a systems approach is considered recognising that almost all factors will interact (n= 1)
- Provide case studies and examples to help people 'buy-in' to the process and manage their expectations (n= 1)
- Provide simple, quick and easy tools that demand little time and resources to reduce time required and keep people motivated (n= 1)
- Provide means of measurement for force, posture and frequency (n= 1)
- Inclusion of data on cost-benefit analysis (n= 1)
- Ability to record whether the requirements are being met (n= 1)
- Inclusion of maintainability and future-proofing (n= 1)
- Ability to maintain/manage single devoted tools such as lifting index for MMH; OCRA for repetitive movement to help expert observation and users' judgements instead of tools that consider all risks for MSDs as a whole (e.g. REBA) (n= 1)

5.6. Discussion

The practitioner survey was conducted with the view of obtaining a preliminary evaluation of the design tool and its elements in terms of its potential and feasibility. The participant information offered a platform to discover the sample characteristics with respect to population data. After that the discussion is extended to compare findings of this study with related literature. Finally, the limitations of the study are discussed.

The occupations, experience and expertise of the practitioners were in general comparable with the results of a previous survey of tools and methods used by 308 certified professional ergonomists (Dempsey et al., 2005). Occupations identified in this study were: ergonomist- 34.1%, consultant- 19.5%, educator- 8.8%, engineer- 5.5%, human factors engineer- 6.5%, manager- 7.8% and other- 7.1% (practitioners were asked to select only one category). The percentage of engineers, human factors engineers and managers in the current survey were each 6.25%, which is also comparable with the previous data. The higher percentage of ergonomists, consultants and lecturers in the current survey may be due to the fact that they were given the option to select multiple categories of occupations. Out of the 308 certified professional ergonomists in the study by Dempsey et al. (2005), 9.1%, 20.5%, 40.6%, 29.2% reported respectively 0-5 years, 6-10 years, 11-20 years and over 21 years of experience. These percentages closely correspond with the findings of the current study. Responses from the study by Dempsey et al. (2005) also revealed that job/task analysis and design (52.9%), health and safety (42.5%) and anthropometry/ biomechanics (34.4%) were the most common areas of expertise. In the current survey, the percentage of practitioners that considered job/task analysis as an area of expertise was 60% and that for anthropometry/biomechanics was 53%. Both studies further show that the occupations and job responsibilities of practitioners are varied. Although the sample in Dempsey's study seems to be predominantly from the United States, there were similarities in their experience giving some confidence in the findings.

With reference to Figure 5.3, practitioners seemed comparatively satisfied with the participatory methods/tools currently being used for 'risk assessment' and 'recording knowledge for improvements/future applications' where the majority of the practitioners have rated greater than 4 in the 7 point scale that ranged from poor to excellent. Lowest mean ratings for the performance were attributed for participatory methods/ tools for 'identifying design solutions', 'presenting user requirements and design solutions' and 'integrating the design process'. In addition, the practitioners do not show any agreement regarding their performance and they would appreciate new tools to facilitate these elements. Ratings for participatory methods currently being used for 'checking feasibility of design solutions' showed a distinctive bi-modal distribution indicating that nearly a half of the practitioners prefer the methods while the others are not satisfied with their performance. This may be due to the background of the sample of practitioners (refer Section 5.5.2) where only a fraction of the practitioners are likely to be accoutred with technical knowledge to effectively check feasibility of design solutions. For example, the sample of respondents consisted of health and safety practitioners and engineers that may have contrasting technical backgrounds. The literature also backs this view by concluding that ergonomics practitioners in general do not get involved later in the design process due to the deficiency in the competency with respect to technical ability, i.e. planning, delivery and evaluation (Williams and Haslam, 2006; Vink et al., 2008). This suggests the need for methods/tools to facilitate practitioners in carrying out these elements in the design process.

Later in the survey, the respondents in general highly rated the importance of all the elements of the proposed design tool (Figure 5.4). Comparison of the performance ratings of the participatory methods/tools currently being used to supplement the elements of the design tool with the importance ratings justifies the inclusion of the guidance material related to the six features of the design tool (refer Section 4.4). Importance ratings also indicate that the practitioners agree to the proposed features of the design tool. Therefore, participatory methods/tools are discussed further according to the elements of the design tool.

Adopting tools and techniques familiar to practitioners in the guidance tool as much as possible would increase the feasibility of the design tool. According to the study by Dempsey et al. (2005), out of the 308 practitioners, 55.5% used body discomfort scale, 51.6% rapid upper limb assessment (RULA), 21.4% Ovako posture analysing system (OWAS), 17.9% rapid entire body assessment (REBA), and 9.1% used posture, activity, tools and handling (PATH). The practitioner survey reveals several comparable figures (refer Section 5.5.3) for body discomfort scale, RULA, OWAS and REBA the percentages were respectively 79%, 79%, 21% and 50%. This variation is likely to be due to differences in the sample composition. The risk assessment tools that were reported to be frequently used by the practitioners were included in the guidance material provided with the proposed tool when it was developed. Furthermore, 21% of the practitioners reported in the current survey that they use the quick exposure check (QEC). Li and Buckle (1999a; 1999b) report that the QEC has been tested by 150 practitioners for sensitivity, usability and inter/intra observer reliability. In addition, it is similar to other posture assessment techniques in terms of the scoring system (David, 2005). This rationalises the inclusion of QEC as part of the guidance material as an alternative method to assess MSD risks. The study by Dempsey et al. (2005) warns that the percentage of practitioners that use a specific tool may not reveal the accuracy or effectiveness of them. In addition, one practitioner indicated that, the ability to maintain/manage single devoted tools such as the lifting index for MMH and OCRA for repetitive movement, instead of tools such as REBA that consider the risks for MSDs as a whole, was preferable. These findings help justify the use of multiple tools and techniques to assess risks, and also defend the inclusion of different useful tools and techniques within the guidance material for practitioners.

According to the survey (refer Section 5.5.3), observation techniques, user interviews, questionnaires and Experience-based judgements are commonly used by practitioners to obtain user requirements. Focus groups were less popular. A literature review by David (2005) also reveals that interview and questionnaire techniques (supported by observations) are used in the industry to obtain self reports on workplace exposure. In addition, it mentions worker diaries and video films as techniques that could be used for this purpose. Many authors (Wilson and Corlett, 1990; Maguire, 1998; Stanton et al., 2005) also indicate that these are popular methods. The proposed methods suggested to help 'identify risks and obtain user requirements' in the design tool are comparable with the methods widely being used by the practitioners in the industry.

The survey (refer Section 5.5.3) reported that the percentage of practitioners that use formal methods to 'prioritise the user requirements' was low (39%). David (2005) states that the scoring systems used in risk assessment methods are largely hypothetical. As a result, using risk assessment scores to prioritise user requirements may not provide accurate results. Advanced techniques to help with prioritising involve video recording of work and the use of computer software, but the time and expertise required is financially demanding (David, 2005). Although quality function deployment (QFD) and proprietary tools were mentioned by the respondents as methods for prioritising risks, the questionnaire was not able to capture details of how these were used. This is a limitation of the survey, and further investigation is necessary.

The responses (refer Section 5.5.3) show that practitioners obtain inputs from different sources to help identify design solutions to the problems identified in the workplace. Unfortunately, the questionnaire did not elicit details of specific methods used by them to help innovate. However, according to the available information, practitioners appear to be broadly using techniques such as brainstorming, experience-based judgements and studying similar cases to suggest new solutions to reduce MSD risk. The literature also suggests using similar techniques to identify solutions to ergonomics related problems. For example, Kuijt-Evers et al. (2009) used a brainstorming technique involving experts to determine solutions to design new hand tools to reduce the risk for MSDs. However, it is not clear what specific techniques they used to induce ideas from the experts. Thus, in-depth evaluation of the proposed design principles to facilitate brainstorming is vital to assess whether the design principles are useful.

The QFD matrix-based tool (refer Chapter 4) was developed with the intention to manage and present design information to enhance communication, and it concentrates on the majority of additional elements that the practitioners thought would be required (refer Section 5.5.5). This is a major aspect of the QFD matrix-based tool and the literature also proposes QFD as a tool for effective communication (Akao, 1990; Chan and Wu, 2002). Moreover, only one practitioner in the current study mentioned the use of QFD as a method used in specific stages of the design process. However, there was no indication of the use of a simplified QFD approach. The literature also supports this. Even though researchers such as Bergquist and Abeysekera (1996) and Marsot (2005) have used QFD to help design ergonomic products, the QFD matrices have been used in the original form without alteration. No literature was found where researchers have attempted to simplify the matrices to help manage and present design information to facilitate communication. Therefore, in-depth evaluation is necessary to obtain feedback specific to the design tool.

Specific methods for ‘recording knowledge for future applications’ were not assessed in the study. However, one of the respondents mentioned that ‘the integrated tool is the computer system and filing is their method of storing knowledge’ (refer Section 5.5.5). This suggests a means of recording knowledge for future use, but no specific techniques were provided. It has been reported in the literature that knowledge reuse is important for effective design, and attempts have been made to provide solutions to the existing problems using knowledge acquired from previous projects (Ramesh and Tiwana, 1999; Moon et al., 2009). For instance, Ramesh and Tiwana, (1999) studied the requirements and developed a prototype knowledge management system. The functionalities of the system include functions for representing context with informal components, easy access to process knowledge, assumption surfacing, review of past knowledge and management of dependencies. There have also been reports on instances where databases have been used when developing design methodologies. For example, Sivaloganathan (1995) describes a software-based design system for concurrent engineering where environments for data and knowledge bases have been proposed. However, specific information related to the integration of databases to manage design knowledge with respect to reduction of work-related MSDs was not found in the literature. The proposed design tool employs a database to record design knowledge, but further investigation is necessary in order to assess its novelty as a concept. In addition, the strengths and weaknesses of this database approach need to be determined.

The questionnaire survey revealed additional elements that the practitioners deemed necessary to make the design tool more comprehensive (refer Section 5.5.5). These needs largely were in congruence with the guidance material further indicating the feasibility of the design tool. For example, the ability to record the ‘rationale behind the user requirements’ was suggested by two of the respondents, and information on the risks and user requirements flow from the tool for prioritisation to the QFD-based tool and then to the database tool enabling the practitioner to trace the origins of the information (refer Section 4.5). ‘Ability to prioritise information and to help designers identify the most appropriate course of action when they had created some concepts’ was also mentioned by two of the practitioners. The colour coding procedure suggested in the design tool to visualise the feasibility of solutions intends to help the practitioners in this regard. Herzwurm et al. (1997) also reported similar requirements such as possibility to easily visualise design information, represent information graphically and record information for knowledge reuse based on a study conducted using 60 German QFD practitioners. However, detailed study of the features of the design tool is necessary to ascertain whether it will work in the industrial setting.

Means of measurement of force, posture and frequency; guidance on cost-benefit analysis and issues related to maintainability and future proofing were not included within the developed guidance material. It was expected that the practitioners possess the ability to estimate force, posture and frequency in the industrial context and record them in the observations and measurements column in the QFD matrix-based tool (refer Section 4.5). Measurements depend on the techniques, facilities and equipment available to the practitioners, and in a literature survey, David (2005) reported that direct measurement techniques appear to be more suited to the investigation of task simulations, as opposed to investigations at industrial locations. Therefore, compilation of these data was thought to be out of the scope of this research.

Information on cost-benefit, maintainability and issues related to future proofing were however considered as important. Inclusion of such design information is also discussed in the literature (Ramesh and Tiwana, 1999; Doultsinou et al., 2009; Moon et al., 2009). For example, Doultsinou et al. (2009) discusses the service issues and service knowledge that has an impact on product design, in particular, how to apply service knowledge in the conceptual design phase. This information could be recorded in the QFD matrix-based tool (in the relationships matrix) and the database tool (in additional fields), and was planned to be included in guidelines within the guidance material to remind the practitioners. However, analysis of cost-benefit, maintainability and future proofing were also thought to be out of the scope of the research because they form different view points of evaluation of designs compared to evaluation of designs to reduce MSDs. Hence, research in these lines is suggested as future work to extend the design tool to increase its comprehensiveness.

5.6.1. Limitations of the study

Although there was a 21% response rate with respect to the registered consultancies, overall, the response rate was low for the online questionnaire (only 32 respondents from possible 1400 individuals or organisations). Greenlaw and Brown-Welty (2009) report from a study that a web-based (online) approach to questionnaire administration is cost-effective compared to paper-based and mixed approaches. Although the response rate for their questionnaire was 52%, the sample (n=1986) of this study consisted of professional members of the American Evaluation Association and 96% of them also possessed postgraduate qualifications. Saunders et al. (2007) gives a more reasonable figure for the response rate and conclude that as a rule of thumb, it can be considered as 11%.

In addition, the newsletter notice in the current study was a general invitation for participation and this can be another reason for the low response rate. However, not all of the practitioners would be involved in reducing MSDs. All these indicate that the sample may not be representative of practitioners in the UK. There is therefore a high risk to the validity and reliability of the results because the responses from those practitioners that did not respond might have completely changed the outcome of the study, and hence, the course of this research. Unfortunately, it is impossible to know the exact reasons for non-response. According to Saunders et al. (2007), there can be several reasons for non-response: refusal to respond, ineligibility to respond, inability to locate respondent and respondent located, but unable to make contact. These may have contributed towards the low response rate.

Out of the total of 32 respondents, only 23 completed the entire questionnaire resulting in a completion ratio of 72%. Some of the practitioners mentioned that they are not involved in the entire design process to reduce work-related MSDs and hence completed only the relevant sections of the questionnaire. Another reason for this may be the effect of the online questionnaire layout design and the number of questions per screen as discussed by Toepoel et al. (2009). However, the guides to questionnaire design available at 'SurveyMonkey' (SurveyMonkey, 2008a; SurveyMonkey, 2008b) were used when designing the online questionnaire. Other literature on questionnaire design (e.g. Oppenheim, 1966; Saunders et al., 2007) was also referred when developing the questionnaire to ensure reliability of the elicited information.

This study adopted a survey technique and provided only an elementary review of the design tool. This is an inherent limitation of questionnaire surveys (Charlton, 2002b). For this reason, an extensive study is quintessential to evaluate the design tool and its elements in-depth in terms of strengths and weakness. Expert evaluation is assessment of a product's usability by an expert while usability tests enable to quantify the extent to which a product meets the needs of its intended users (Rosenbaum, 1989). These approaches need to be used in order to evaluate the design tool in-depth.

The performance and the importance ratings for the elements of the design tool were evaluated using only the frequency distribution of the ratings. Performance of mathematical operations is neither appropriate nor recommended with ordinal data obtained using rating scales (Annett, 2002). Therefore, only qualitative comparisons were made to assess the elements of the tool, and mathematical comparisons of the Likert type scales were not performed due to the fact that these essentially provide subjective ratings (Clason and Dormody, 1994; Göb et al., 2007).

5.7. Summary

The online questionnaire survey was conducted to evaluate the feasibility of the design tool (and guidance material) with respect to current practice. In all, although only 32 practitioners responded to the survey, the findings will have value in furthering development of the design tool. Ratings of the performance of participatory methods available to the practitioners to facilitate in the design process were mostly varied and distributed throughout the range of the scale indicating a need for effective and efficient methods. The ratings of the importance of the elements of the design tool were in general high. In addition, the majority of the practitioners highly rated the importance of an integrated approach for participatory design to help reduce work-related MSDs. They also made suggestions for the proposed design tool and these were in congruence with the features already present in the tool. The questionnaire technique is only one of the approaches to evaluate a product or a process and has limitations such as the inability to obtain detailed assessments. Therefore, further investigations need to be conducted in order to evaluate the design tool in-depth.

6. Practitioner interview study

6.1. Introduction

The previous chapter (Chapter 5) elaborated on the results of the questionnaire survey of practitioners to assess the feasibility of the design tool. However, further investigation is necessary to evaluate the tool and guidance material in more depth in terms of its feasibility, strengths and weaknesses. Interviews can provide detailed information on specific issues (Creswell, 2007; Saunders et al., 2007); therefore, an interview study was carried out with a subset of practitioners that responded to the practitioner survey. The objective was to evaluate the strengths and weaknesses of the design tool in the field setting and make recommendations for using the tool in this context (refer Chapter 1: Objective 4). In this pursuit, the following sub-objectives were identified:

- To further evaluate the feasibility of the design tool and guidance material;
- To understand the capabilities and limitations;
- To identify directions for future development.

6.2. Sampling

Out of the 32 practitioners that responded to the practitioner survey, 19 expressed an interest in taking part in further research. Three from the 19 that positively responded were from outside the UK, and therefore for practical reasons, were excluded. Hence, 16 respondents were identified for face-to-face in-depth interviews.

Participation in the interview study was voluntary. At the start of the session, the nature of the interview was explained and informed consent was obtained (Appendix 6.1 and Appendix 3.2). The Loughborough University ethical guidelines (Loughborough University, 2003) for studies involving human participants were observed.

6.3. Data collection

An interview guide was initially developed, and was piloted with two work colleagues. In this version of the interview guide, rating scales were used to rate the performance of the different aspects of the design tool. However, after piloting, it was decided to remove these scales as the pilot sample mentioned that it is difficult to rate the performance of the design tool and its features without using it.

The purpose of the study was discussed and the date and time for the face-to-face interviews were arranged. The web link to the online design tool (www-staff.lboro.ac.uk/~huhkgp) was made available to the practitioners by email a week before the interview date.

Prior to the interviews, the design tool was demonstrated to the practitioners using a verbalised walkthrough approach (Stanton et al., 2005). Each of the six features in the tool was demonstrated using an example to facilitate the process. After that, face-to-face in-depth semi-structured interviews were carried out to obtain feedback on the feasibility of each of the six features of the tool. The interview guide (Appendix 6.2) consisted of questions to assess the positive aspects and limitations of the design tool; the appeal of the tool in the field environment, and views on any changes or alterations/modifications needed. Practitioners were also asked about the alterations/modifications required with regard to the integrated approach. Probing questions were asked as necessary. Interviews were audio-recorded using an Olympus® VN-2100PC digital voice recorder to ensure uninterrupted flow of the discussion. At the end of the interview, the practitioners were asked if they were willing to try out the tool in one of their projects.

6.4. Analysis

Background data on the practitioners that took part in the interview study was obtained from the practitioner survey questionnaire. Relevant material from the interviews was identified from the audio recordings and was transcribed by playing back in RealPlayer® version 1.0.1. This was followed by content analysis of the data following a similar procedure to that of the user requirements study (refer Section 3.4).

Practitioner comments/opinions regarding the integrated approach were initially extracted from the narratives and compared. Then, the themes were classified according to the six features of the design tool. These were further categorised according to capabilities/feasibility, limitations and future development to address the objectives of the study. The themes were listed in a priority order depending on the number of participants that mentioned a particular theme. Finally, the findings together with the literature were used to carry out minor changes to the design tool.

6.5. Results

6.5.1. Participants

Eight out of the 16 respondents that indicated their interest in participating in further research were available for the interviews (five males and three females). Using the data from the questionnaire survey, the participants reported their roles as ergonomists (63%), consultants (38%), lecturers (38%) and engineers (13%): three reported more than one category of occupation. All reported managing ergonomics projects as one of their job responsibilities. Others were, conducting user trials (88%), user needs analysis (75%), equipment and task design (63%), user measurements assessment (38%) and MSD risk assessment (25%).

Table 6.1 shows the experience of the practitioners. The majority (63%) reported over ten years of relevant experience.

Table 6.1. Experience as a practitioner (years of experience and percentage of practitioners) (n = 8)

Experience (years)	% respondents
0 - 5	12
6 - 10	25
11 - 20	25
≥ 21	38

Areas of expertise reported were product/system development (75%), user requirement analysis and specification (75%), evaluation of products/systems (75%), product/ system design and testing (63%), job/task analysis (50%), anthropometry/ biomechanics (38%), participatory ergonomics (38%), evaluation of MSD risk (25%) and systems analysis and design (25%).

The interviews took 45 - 90 minutes and the views of the practitioners were categorised according to capabilities/feasibility, limitations and future development. Initially, their views on the overall tool and the approach are presented followed by opinions on the features of the design tool itself. Finally, the changes that were incorporated to the design tool are listed.

6.5.2. Evaluation of the integrated approach

The themes identified from the practitioner narratives concerning the design tool as an integrated approach are summarised in Table 6.2. Overall, opinions were positive, indicating the feasibility of the design tool. However, the majority of the participants also mentioned limitations, and all of the practitioners suggested remedial action to address these and had suggestions for the future development of the tool.

Table 6.2. Evaluation of the integrated approach (within brackets, number of practitioners expressing views)

Capabilities/feasibility	Limitations	Future development
Tool will help collaborate/communicate with others [4]	The entire process is long and may take a lot of time [4]	Provide guidance on how to use the tool [8]
The tool will guide the practitioners through the process [4]	May not work with every project [2]	Automate the procedures [6]
Good to have the flexibility to omit or alternate between features [3]		Make it possible for the online tool to be updated collaboratively [2]
Tools may be adapted [2]		Develop to generate reports [1]
Has captured the ability of QFD to simplify the complex issues in the design process [2]		Make it suitable for big projects [1]
Good to have resources within the guidance material [2]		
Similar to the procedure one would normally follow [2]		
Procedures would be easy after the approach becomes familiar [2]		
Tool will work for complex problems [1]		
Individual tools are appealing [1]		
Good to have the tool online [1]		

Capabilities/feasibility	Limitations	Future development
Good to have used Microsoft® Office to develop forms [1]		
Procedures can be carried out without the involvement of all stakeholders [1]		

All eight participants were positive about the design tool and thought it would be useful, and this signifies its potential in industry. Half of the practitioners supported the notion of enhanced communication among the stakeholders of design through the use of the design tool. They emphasised the tool's potential in facilitating the communication of design requirements to practitioners of design such as engineers. For instance, participants 4 and 5 mentioned:

> *Yes, I think it* [design tool] *probably would work. Yeah. Yeah. Because the design engineers, you know, would normally use QFD for such kind of process, but they have to collect the user requirements by themselves, and you know, and it requires quite a lot of effort. So, if somebody has already done that for them, and also done some prioritisation in terms of where and whereabouts of the effort should go, I mean, they would be very happy about it.*
>
> Participant 4: practitioner interview study

> *For the more complex situations you do need a tool and you need more people involved so you can explore what they have got to offer in terms of their knowledge and expertise working in this sort of area… So if you've got any representatives of ergonomics, health and safety, engineers, designers, you got a multidisciplinary team then you cover a broader scope and also makes it easier to identify the relative feasibility. I can see that being very useful.*
>
> Participant 5: practitioner interview study

Also, four of the practitioners stated that the tool will guide the practitioners through the design process. For example, practitioner 3 stated:

> *I am always interested in things, which, kind of, encapsulate. I think there are some nice ideas in here and I like it and I can see the way in which you can logically take people, engineers being sceptics, through a process saying it is a cut through this* [process] *and these are the answers and if you got some more you want to add yourself and it's a way of recording that process.*
>
> Participant 3: practitioner interview study

Some practitioners indicated the capability of the tool to omit or alternate between features, again signifying its feasibility in the industry. Excerpts from the narratives of participant 1 and 2 are quoted as examples:

> *It's good to have this in the internet. Any company that took this* [design tool] *on would probably want their own version sitting in their own intranet because they* [companies] *can adjust it to their liking…. Yes, they* [practitioners] *would certainly need something like this.*
>
> Participant 1: Practitioner interview study

> *I can see it being a tool actually practitioners really like, learn how to use it and then they will also develop their own personal methodology out of it and possibly stop using it. You know, taking away some of the design principles, the way that you suggested might not work the way they want. And then they might abandon the tool, but having said that, what you have given them makes them develop their own methodology that incorporates much of this or some of this depending on their wok context. So I think it will be very useful in that sense.*
>
> Participant 2: Practitioner interview study

While commenting on its feasibility in industry as an approach that could potentially help in reducing workplace risk factors for MSDs, all of the practitioners also had reservations. Half expressed that the entire process was long and time consuming. For instance, participant 4 mentioned:

> *Again, my only concern is the amount of time it takes to go through the six steps. … And it's the time element that makes the functionality of the system itself. We do the questionnaire then we have to go through the*

whole questionnaire and identify what we want to take out; what the issues are. Then, from issues we put it into something else and now is to say what the priority is and that list we put into the matrix and you need to go back and see what the solutions are and it's not always easy to find the time to do all of that. You will be asked a question one day and you are expected to find the solution the next day. It probably takes months after that to actually implement the solution, but they expect quick turn points.

Participant 4: Practitioner interview study

All practitioners stated that more guidance is required for the future development of the tool. For instance, practitioners 3 and 8 suggested:

I think I quite like it [the design tool]*, but you need to have some more explanations. May be some pictures. It always helps.*

Participant 3: practitioner interview study

To understand, you need to have a session like you are having. That means guidelines are required.

Participant 8: Practitioner interview study

Six of the practitioners also suggested improvements to the procedures through automation, for example, participants 7 and 8 mentioned that:

The entire process is quite long and time consuming. Ensure that practitioners are aware of this when using it. It is possible to perhaps have a modified version which can be done quickly using automated aspects of the entire process? That can be presented as a guide at the beginning of a project and then the more detailed process can be applied.

Participant 7: practitioner interview study

You need to have matrices for each of the sections, which may increase the workload. This may be handled using an automated system.

Participant 8: practitioner interview study

6.5.3. Identifying risks and obtaining user requirements

Evaluation regarding the guidance material for 'identifying risks and obtaining user requirements' is summarised in Table 6.3. The majority of the practitioners identified that the methods included in the design tool were feasible. The themes concerning 'capability/feasibility' also indicate the flexibility that the tools and techniques offer to the practitioners to help identify workplace risk factors for MSDs. However, the dearth of guidance for practitioners was a major limitation.

Table 6.3. Evaluation of guidance material for 'identifying risks and obtaining user requirements' (within brackets, number of practitioners expressing views)

Capabilities/feasibility	Limitations	Future development
Has a set of tools that could be readily used [5]	Not enough guidance on how individual methods are used and selecting methods to collect data [6]	Provide more guidelines (e.g. selecting methods, data collection, sample sizes) [6]
Helpful for inexperienced practitioners [5]	Co-operation of workers is necessary but difficult [2]	Include more sources of information [2]
Checklists and guides will help [4]	Standards and guidelines regularly get updated [1]	Provide decision support by simply using a flow chart [1]
Standard methods in ergonomics are used [1]	There are methods that are not used in subsequent steps [1]	Provide references to the techniques [1]
Information on standards and guidelines is sufficient [1]	Separate risks and requirements as they are different [1]	Have standards and guidelines at the bottom [1]
Ability to triangulate data is good [1]		Provide guidance on separate sheets [1]
Ability to download and modify according to the need [1]		Need to capture the reasons for requirements [1]
Ability to obtain detailed information [1]		Have provision to collect psycho-social factors [1]
Practitioners can also use methods they are familiar with [1]		

As can be seen in Table 6.3, majority of the practitioners appreciated the availability of procedures that could be readily used and thought this would be beneficial, especially for the inexperienced practitioners. For instance, participant 3 mentioned:

> *One of the things I saw when I was going through this is that me being lazy it's always nice when you have these things. We have to actually get the thing and you know you have to go away and sort things out elsewhere and it's a nuisance. Probably, I would not bother to do that, whereas this, because it's there, it's really convenient you know. For practitioners, definitely being able to have a thing there is really useful. You see what it is and you can use it straight away.*
>
> Participant 3: practitioner interview study

However, the most frequently mentioned limitation was the lack of guidance on selecting appropriate methods. For example, participant 5 pointed out:

> *You've got the interview, which is self explanatory. It depends how much you want somebody to do over and above. … Obviously there is a lot of information there. Do I need to do only one? Do we need to do it all? Do we need to do some of it?*
>
> Participant 5: practitioner interview study

Participant 6 shed light on the guidance material, especially targeting practitioners with little experience:

> *… I mean you've got the techniques there, you don't say whether you do one or both or whether you should definitely use REBA. If it's for experienced practitioners ergonomists, you probably don't need much. Otherwise, people with less experience, you might, without filling this page too much perhaps you can write a bit of general guidance and have that as another document that you can print off. I think it's more like when is a good time to do interviews. When is a good time to do observations, and a few hints and tips on doing them I think. Something you could follow up like references.*
>
> Participant 6: practitioner interview study

6.5.4. Prioritising the risks and user requirements

All themes concerned with prioritising the risks and user requirements are summarised in Table 6.4. All of the practitioners considered this element as important and feasible.

Table 6.4. Evaluation of guidance material for 'prioritising risks and user requirements' (within brackets, number of practitioners expressing views)

Capabilities/feasibility	Limitations	Future development
Tool developed to prioritise user requirements is important and useful [8]	Might miss out on important requirements [2]	Guidance is required to understand the process [5]
Prioritisation is carried out in a systematic way and provides objectivity to softer data [5]	Too time consuming [1]	Provide guidance on how to identify themes [2]
Audit trail is possible [1]	Cost implications are not considered when judging the priority [1]	Format for paper size because practitioners may perform content analysis on paper [1]
Ability to identify the frequency of comments helps look into such areas [1]		Need to insert a multiplication factor to estimate the total number of workers affected since only a sample is used to collect data [1]

All practitioners considered that the Microsoft® Excel-based tool concerned with prioritising risks and user requirements was important and useful indicating its capability as a procedure to help practitioners with prioritisation of design requirements in a systematic manner. Five also mentioned that the prioritisation tool gives objectivity to qualitative data. Participant 7 explained why the tool is important.

> *Being able to identify the frequency of comments and create themes from the users themselves, users will feel involved in the changes and the risks identified by the users that may have not been considered in-depth by the assessor. This may also have the biggest impact on improvement as they are identified by the workers.*
>
> Participant 7: practitioner interview study

Only half of the practitioners mentioned specific limitations. Reliability of the prioritised list of requirements obtained using this tool was a caution indicated by two of the practitioners and in particular the possibility of leaving out important requirements. For instance, practitioner 3 pointed out:

> *Ok. That's cool. It gives at least some sort of you know… So it is to bring objectivity into softer data isn't it? I think the engineers would like that because it's got numbers to it. It may be only one person who has mentioned this, but it can be a critical one because users have different experiences…areas identified may not actually be a priority and have to be mentioned to create a theme.*
>
> Participant 3: practitioner interview study

The majority of the practitioners thought that more guidance was needed in order for them to use the tool without assistance. For example, participant 6 said:

> *May be it's not a bad idea through each of these steps to have a one page sort of guide on how to do it, but not in detail, with something for a person who isn't sure to have a look at. Even if it's a very simple and practical like, now you are going to fill in this themes table and go through each interview record in turn. For the first one, underline the main themes. Fill in the first column. Then, move on to the next script for the second person. Do the same, bearing in mind the themes that were from previous ones, and fill out the matrix accordingly. I think little things like that. That's what I probably propose.*
>
> Participant 6: practitioner interview study

6.5.5. Identifying design solutions

Comments regarding the guidance material to identify design solutions are summarised in Table 6.5. Although there were concerns regarding this feature of the tool, all of the practitioners were positive that it could work in the industry.

Table 6.5. Evaluation of guidance material for 'identifying design solutions' (within brackets, number of practitioners expressing views)

Capabilities/feasibility	Limitations	Future development
It is a very good tool that will work in the industry [8]	Does not give an idea of how to use the design principles in a problem [1]	Provide guidance on how to use the tools [7]
Design principles will be very useful to practitioners to generate creative ideas and to communicate [7]	Does not give prominence to ideas that come without the aid of the design principles [1]	Have provision to include cost/benefit information in the matrix (number of workers affected/saving) [3]
	Does not readily cater for changing requirements [1]	Have provision to include photographs, sketches etc. in the QFD-based matrix [2]
	Not sure how much the correlation matrix will help [1]	Descriptions of design principles can be made more MSD related [1]
		Include other creative thinking techniques [1]
		Link the design principles to the QFD-based matrix [1]

All appreciated the fact that the tool will be useful for industry. Seven out of eight mentioned that it will also be very useful in generating creative ideas and communication regarding MSD related problems. For example:

> *Having design principles that facilitates you making proposals on how you like to change the design or whatever. … It would make a huge difference in their ability, to be able to give something useful to the design engineer.*
>
> Participant 2: practitioner interview study

I like the design principles. I've not come across this before. There is a sort of distinction that people make between when you've got a problem, applying sort of low level fixes, or rethinking the whole problem going in to a higher level. Perhaps thinking of a whole new approach, which could solve the problem in a completely new way.

Participant 6: practitioner interview study

The QFD-based matrix was developed to list the requirements for design; corresponding solutions and other useful information related to a project. It was generally liked by the practitioners, but there were also some concerns. Again, the main theme was lack of guidance available for the practitioners to use the tool effectively. For instance, participant 4 suggested that:

Correlations: I like it, but I am thinking it might be confusing for non experts, people who don't know what's going on, P's and your N's, I know it's positive and negative and know how to go around. And again the way it's laid out it confuses me, but it might be just because I have not come across myself. So it's a case of trying to understand it. Once I understand it, I may be able to get across it better.

Participant 4: practitioner interview study

6.5.6. Selecting acceptable solutions

A summary of themes identified regarding capabilities/feasibility, limitations and requirements for future development of the tool is in Table 6.6.

Table 6.6. Evaluation of guidance material for 'selecting acceptable solutions' (within brackets, number of practitioners expressing views)

Capabilities/feasibility	Limitations	Future development
Colour coding solutions is good [5]	Difficult to judge whether green, amber or red [3]	Provide more information on assigning colours [4]
It is good to be able to check relative feasibility of the solution [3]	Taking only the green solutions forward may have a potential problem [2]	Colour coding system needs to be consistent and intuitive [4]
		Keep amber and red solutions as well [2]

Capabilities/feasibility	Limitations	Future development
		Flow chart to guide through the process [1]

The colour coding systems proposed within the design tool to visualise the solutions in the order of feasibility was appreciated by the majority of practitioners. For example, participant 4 commented that:

> *Your red, amber, green. That's great because we use it quite as a status. So that's a good one.*
>
> Participant 4: practitioner interview study

However, four of the practitioners also pointed out potential shortcomings in the colour coding system and suggested changes. Examples are quoted from the narratives of two practitioners:

> *To consider something red, yellow or green, I think you need to have a more like the same scale. At the moment, it seems that there is a difference. In that case, could you show something like a flow chart to help you decide? So that you can say this is technically feasible- yes or no. Is it giving rise to new harmful effects? Yes or no. You could almost have a simple flow chart.*
>
> Participant 6: practitioner interview study

> *I agree, the traffic light system will always mean, red would mean something like it's too difficult or it's technically infeasible beyond the laws of physics or something like that. Amber would be ok there are possibilities, but there are potentially some significant problems need to be overcome. With time and effort you will be able to solve it. And green would be either it's easy to do or it absolutely solves the problem. That would be my simple interpretation of that without reading your rules.*
>
> Participant 3: practitioner interview study

6.5.7. Presentation of risks and user requirements, and solutions

Table 6.7 gives a summary of the themes identified regarding presenting design information. All of the practitioners were very positive about the capability of the tool in presenting and visualising design information. Comparatively, there were only a few comments regarding the limitations and directions for future development.

Table 6.7. Evaluation of guidance material for 'presentation of risks and user requirements, and solutions' (within brackets, number of practitioners expressing views)

Capabilities/feasibility	Limitations	Future development
It will be a useful tool for presentation [8]	Not able to breakdown the matrix into sections (some stakeholders may need to see only a part of the matrix) [3]	Make it possible to breakdown the QFD-based matrix in to sections [3]
The approach will help visualise all the design information effectively using a single interface [8]	The matrix may become large and difficult to manage [2]	Provide guidelines on how to complete the matrix [2]
Will help to take the stakeholders through the process [5]		Have provision to show a group of solutions rather than the minimum number [1]

All of the practitioners liked the usefulness and comprehensiveness of the QFD-based tool for presentation and commented on its ability to help easily visualise design information. For example:

> *Again from an aerospace point of view there are some restrictions. Even if we came up with a requirement, the engineers will knock it back. Presenting it in a format that's compatible with their thinking is very good. And it takes so much trying to build that transition between the ergonomists and the engineers. We are very systematic in our thought process in our disciplines but there is a disparity. Absolutely! So bringing in engineering tools into this field is fantastic.*
>
> Participant 4: practitioner interview study

The ability of the QFD-based approach to effectively communicate the design information was considered as an important aspect of the tool by all of the practitioners. For example, one participant stated:

> *I quite like that presentation. I think it's helpful when presenting solutions to engineers or anybody actually that you can take them through the story. So, rather than presenting them with the answers, that, you would take them through your previous one, because they can see where they come from and why you made the decisions you've made. People are always suspicious about being told this is the answer.*
>
> Participant 3: practitioner interview study

Three of the participants further mentioned that being unable to breakdown the matrix into sections is a limitation, and it would be important to be able to split the matrix easily when required. For example participant 8 said:

> *How can you show such a large spreadsheet to somebody when the spreadsheet gets big? And when you are going to one side, you are missing the solutions on the other side. You can't compare, but I don't know how you get around it. Have a format, which you can present.*
>
> Participant 8: practitioner interview study

6.5.8. Recording knowledge in a solutions database for future use

Table 6.8 provides a summary of the themes concerning capturing knowledge for future use in projects.

Table 6.8. Evaluation of guidance material for 'recording knowledge in a database for future use' (within brackets, number of practitioners expressing views)

Capabilities/feasibility	Limitations	Future development
The database will be helpful in managing information [7]	Practitioners will not spend time filling the database [4]	Make it possible for practitioners to collaboratively update and use [3]
Practitioners will be able to use the saved information [2]	This might only work where there are dedicated people to do it [2]	Have another column to include the context [1]

Capabilities/feasibility	Limitations	Future development
Using drop down menus is good [1]	Practitioners may rely solely on the database rather than looking at new solutions [1]	Add a field to have cost details to make it possible to sort according to cost [1]

The majority of the practitioners considered the solutions database to be a useful tool. However, half of the practitioners also thought that it would be additional work for them to update it. For example,

> *Yes, it* [solutions database] *has the rigour of record keeping and all that stuff. I probably wouldn't bother, but I might come to a situation where actually I wish I had. You may be right. Are these linked automatically? Again as a practitioner and being lazy, I would probably, if I had to retype all this stuff, think I don't want to do that, I would be either looking to have automatically done for me or to say actually take the previous one* [QFD-based matrix].
>
> Participant 3: practitioner interview study

Also, three of the practitioners provided an insight into making it possible for them to update it collaboratively. Practitioner 2 mentioned:

> *If you can have a solutions database that many people contributed to, a team of practitioners, you have access to information from processes of other practitioners have gone through I think it will be very very useful.*
>
> Participant 2: practitioner interview study

6.5.9. Changes to the design tool

At this stage of the research only simple changes that would not require much time were carried out, as there were time constraints due to the case studies that were planned.

Two practitioners suggested the importance of including more sources of information (especially, European standards and guidelines) within the guidance material. Therefore, in accordance with this, the following were included with the guidance material:

- The manual handling assessment chart (MAC) developed by the HSE (2003).
- The web resource for UK defence standardisation DSTAN (2009), which provides vast details on standards and guidelines that are being developed by the ministry of defence, UK.

Five practitioners stated that more guidance was required to facilitate prioritisation of the risks and user requirements. Two of them also suggested moving the guidance that was already included to the top of the worksheet. In response, further instructions were included to guide practitioners in entering and analysing themes, and the material was moved to the top of the worksheet. Furthermore, the worksheet was formatted so that it could be printed out on A3 size standard paper. Other suggestions for future development are proposed as future work in Section 6.6 and further discussed in Chapter 8.

6.6. Discussion

Initially, the characteristics of the practitioner sample are discussed, followed by a discussion of the strengths, weaknesses (limitations) and directions for future development of the design tool, and finally the limitations of the study.

In the practitioner interview study, reported job roles were 63% ergonomists, 38% consultants, 38% lecturers and 13% engineers. In a similar study of 308 certified professional ergonomists (Dempsey et al., 2005), there were a lower proportion of ergonomists (34.1%), consultants (19.5%) and educators (8.8%), but the percentages of engineers (i.e. engineers- 5.5% and human factors engineers- 6.5%) were comparable. However, in this study, the practitioners have been asked to select only one category. Furthermore, in the current study, 12%, 25%, 25% and 38% reported respectively 0-5 years, 6-10 years, 11-20 years and over 21 years of experience. In the same study conducted by Dempsey et al. (2005), the corresponding figures were 9.1%, 20.5%, 40.6% and 29.2% and comparable with the current study. The estimated median of years experience of the participants in the current study is 13.6 years. A study by Williams and Haslam (2006) with 107 ergonomics related practitioners and academics from different parts of the world showed that the average years of experience of the participant group as 13 years, which is comparable with the finding of the current study.

One of the objectives of developing the design tool was to enhance communication among the stakeholders of the design process. This was found to be an important capability of the design tool by practitioners in the current study. Half explicitly mentioned that the tool would help them collaborate/communicate with others referring to the overall integrated approach to design (refer Section 6.5.2). In support of this, while evaluating the tool for 'presentation of risks and user requirements and solutions', all of the practitioners mentioned that this will be useful, and help them present and visualise design information effectively. In addition, seven of the practitioners stated that the design principles included as an element of the tool would be useful to communicate ideas. These findings support the notion that the tool enhances communication in the design process. No specific studies could be found in the literature to justify this claim.

However, the literature on quality function deployment (QFD) explicitly mentions that it has been developed as a tool to effectively communicate design requirements from the users to the design teams to ensure design quality (i.e. the degree of compliance between the designs and the user requirements) of both products and processes (Akao, 1990; Day, 1993; Terninko, 1997; Reich, 2000; Chan and Wu, 2002). Interestingly, Lager (2005) concludes from his work that industrial applications of QFD are instrumental in making products meet requirements and for improving the information dissemination and retrieval processes. This helps to substantiate the views of the practitioners regarding the tool's capacity to manage design information and enhance communication.

Researchers also practice and advocate the idea of integrating QFD with additional tools and techniques to enhance its performance in the design process (e.g. Gonçalves-Coelho et al., 2005; Chin et al., 2005; Lin et al., 2006; van de Poel, 2007). For example, van de Poel (2007) discusses integration of techniques such as Kano's model to ensure customer satisfaction, sophisticated rating scales to more effectively relate customer demands to engineering characteristics and methods to set targets for both customer and engineering characteristics would help alleviate its inherent methodological problems. These studies also support the use of a simplified form of QFD with supplementary methods, tools and techniques to facilitate communication in the design process, especially in the initial stages of design.

Another objective of the design tool was to facilitate the practitioners in working through different stages of the design process. This was identified as one of the strengths of the tool by half of the practitioners (refer Section 6.5.2). Supporting this view, most practitioners liked the fact that the prioritisation of design requirements is carried out in a systematic way. The design tool closely follows part of the 9-step participatory process developed by Vink et al. (2008). It also closely matches with the phases of design models such as the Archer's prescriptive model described in the literature (refer Section 2.6). These indicate some validity in the practitioner comments.

According to literature, design methods such as QFD have been developed to facilitate practitioners in the design process (refer Section 2.7), with which the practitioners in this study seem to agree. For instance, referring to the integrated approach, two of them could align the QFD-based approach to the process they would normally follow. Again, the ability of it to be integrated with other methods such as those discussed by Chin et al. (2005) and van de Poel (2007) to enhance its performance makes QFD an adaptable tool that can fit into different contexts. This property of QFD has been extensively discussed in Section 2.7.7 and Section 4.2.2. These also lend credence to the practitioner views regarding the ability of the QFD matrix-based tool to integrate the phases and guide the practitioners through the design process.

Understanding the findings related to the specific features of the design tool provided further insights pertinent to its potential. Interestingly, the majority of the practitioners had positive comments regarding all of the elements. For example, the majority thought that the tools and techniques provided in the guidance material to identify workplace risks could be readily used and be especially helpful to inexperienced practitioners. All the practitioners appreciated the importance of the tool's ability to prioritise the findings/ themes in a systematic manner providing objectivity to softer data. All of the practitioners were enthusiastic that the QFD matrix-based tool would work well in industry and be useful for the presentation and visualisation of design information.

Making it possible to guide the practitioners by providing structure to the design process is an aspect reported in the literature with respect to using design methods to facilitate every procedure in the design process. For example, Green and Bonollo (2004) discuss that design methods help guide practitioners by providing structure and resources to complex design issues, and help deal with excessive amounts of information in the design process effectively. These methods make the practitioners aware of the often overlooked aspects of design such as regulations, functional attributes, cultural differences and user centred design. This discussion indicates why the practitioners in general appreciated the inclusion of methods, tools and techniques in the guidance material to facilitate different activities in the design process.

While appreciating the potential and feasibility of the design tool, the majority of practitioners also mentioned limitations. The foremost limitations identified were; the time that may take to complete the process and the possibility of not being applicable to every type of project (refer Section 6.5.2). Again, it is not possible to directly relate these findings to other studies simply because the design tool discussed in this research project is novel and unique. However, it would be opportune to discuss the findings with respect to comparable tools. Comparable issues are identified by Bruce et al. (1995) with regard to collaborative product development, where they discuss that the alleged benefits of collaboration may not always be achieved in practice. Consequently, it is important to pay attention to managerial and other factors such as resource allocation for product development that may influence the outcome of collaborative product development.

Similar problems are also highlighted by Franceschini and Rossetto (1998) where they report that management difficulties increase exponentially with the increase in scale of design projects thereby affecting the size of the QFD matrices. In relation to a study on assessing the usability of QFD using nine industrial applications, Lager (2005) concludes that the often-cited claim, ‘shorter time-to-market’ does not hold valid and has no scientific backing. This finding emphasises that the QFD process naturally would take time due to the elaborate structured procedures that need to be followed in order to obtain reliable results, and this may be the shortcoming envisaged by the practitioners in the current study regarding the time factor. These issues may be the basis for views such as ‘time to complete the process’ and the ‘possibility of not being applicable to every type of project’ from the practitioners.

The most frequently mentioned limitation regarding the features and the individual elements of the design tool was the inadequacy of guidance to enable effective use of the tool itself. For example, with respect to the guidance material for the first feature (i.e. identifying risks and obtaining user requirements), the lack of information on the selection and use of individual methods was mentioned as a limitation. In addition, the following were also mentioned as requirements for future development by the majority of practitioners. These can again be related to the same limitation: the lack of guidance.

- Further guidance to understand the process prioritisation of ‘risks and user requirements’.
- Guidance to use the tools and techniques included to ‘identify design solutions’.
- More information is needed to help assign colours when ‘selecting feasible solutions’.

In the current study, two of the practitioners also perceived that the procedures would become easier with familiarity. This also seems to be in line with the limitation regarding guidance elaborated above, and indicates the need for familiarisation with the tool in order to use it effectively. Developing guidance has been extensively discussed in the literature and often resulted in significant challenges to product and process developers. For example, Pham and Dimov (1999) discuss the importance of providing assembly information in manufacturing, and detail an approach to present feature-based design models such as technological requirements and assembly hierarchies to understand the assembly processes of products.

Guidance (documentation) is particularly a problem widely discussed in software engineering. For instance, Kendall and Kendall (1999) describe that system analysts fail to document the systems they develop properly due to a multitude of factors such as time availability, use of improper methods and analysts being in general reticent about documenting. For these reasons, the systems are not understood by the intended users. Rettig (1991) states with respect to software documentation that: "I*f you are designing software, you owe it to those you serve to gain an enlightened attitude toward documentation, recognising the inter-connectedness of the software, its documentation and the help system. Otherwise, you are not a practical programmer.*" Thus, providing guidance in using the tool at every stage of the design process is of utmost importance. In the current research, the basis for limiting the guidance included in the tool was due to time constraints.

Another frequently mentioned limitation of the guidance material was the time needed to go through the procedures included. For example, half of the practitioners stated that they would be reluctant to spend time in filling the database. However, in contrast, two others stated that the tool could help simplify complex issues in the design process. This debate is encapsulated in previous research with respect to design methods (Green and Bonollo, 2004). They discuss that, design methods clearly provide a structured approach to the design process to help practitioners take into account the aspects that are usually neglected. In spite of this, experienced practitioners repudiate methodological techniques for three main reasons: (1) practitioners over time develop a knowledge-base of expertise that facilitates effective design decisions; (2) methods are cumbersome and significant input of data and paperwork is time consuming and (3) formal design tools are not always taught in practice. This discussion can be directly related to the findings of the current study and appropriate guidance can be incorporated accordingly in the future to help practitioners.

Overall, comments on the capabilities and feasibility of the tools and techniques included in the guidance material outweigh the limitations with respect to every feature of the design tool. The QFD matrix-based tool and the design principles that encompass features to identify solutions and present design information could be judged as the most important of the elements according to the practitioners. The tool for prioritisation was also well received. Importantly, no limitations were identified that would potentially inhibit the progress of the research project, and the limitations and suggestions for future development reported by the practitioners provide significant impetus towards the advancement of the tool. Furthermore, practitioner ideas to rectify these problems were important in understanding what is expected by the practitioners from a design tool of this nature. Suggestions for future development of the tool are:

- Include step-by-step guidelines to facilitate understanding of the methods and tools made available in guidance material.
- Automate the repetitive data entry procedures to reduce the amount of time required to complete the procedures.
- Make it possible to collaboratively update the design information.
- Develop the ability to breakdown the QFD-based matrices into sections to help present design information.
- Make provision to include cost/benefit information in the QFD-based matrix.
- Make provision to include photographs and sketches in the QFD-based matrix.

Herzwurm et al. (1997) studied the user requirements for the development of a software tool to facilitate use of the QFD process. They involved 60 QFD practitioners in Germany and obtained 27 requirements, which were later categorised into 11: easy to use and learn; adaptability to be used in different applications; ability to use collaboratively with other users; possibility to exchange data with other programmes such as Microsoft® Excel; ability to document data; generate outputs for visualisation; possibility to represent graphically to help analysis; ability to reuse data; ability to integrate other methods; support for introduction (guidance) and supplier support such as training. Interestingly, these requirements are comparable with the majority of the current findings in relation to suggestions for future development of the tool. In addition, Herzwurm et al. (2003) studied seven of the most important commercial and three of the most important non-commercial software tools that support QFD. They conclude that users were generally satisfied with the most of these tools. Despite this, the majority of these software tools received negative responses in terms of the ability to use collaboratively with other users and integration with other methods. Interestingly, these were important aspects of the design tool that the practitioners mentioned during the interviews. It must also be noted that the software tools studied were based on the original QFD approach, whereas the design tool presented in this thesis is based on a simplified/modified QFD house of quality matrix. Therefore, the QFD software tools discussed in the literature are unlikely to be readily used by practitioners to enhance communication in the design process and help reduce work-related MSDs.

Combining web-based and software-based approaches with the design tool to help effectively manage design information is therefore important for its future development. Similar approaches are reported in the literature with regard to collaborative design. For example, Sudarsan et al. (2005) describe a framework that captures product design rationale, assembly and tolerance information from the earliest conceptual design stage to facilitate a product lifecycle management (PLM) system. Within this framework, designers are able to understand the function and performance of products in the full lifecycle and use computer-aided design, engineering and manufacturing (CAD/CAE/CAM) technologies. The PLM system, which is a computer-based technology, enables data management within the framework. In addition, Sharma (2005) states that, with the rapid progress of technology, PLM as a concept is becoming practical. Therefore, technologies such as these could be taken into account when identifying directions for future development of the tool. This is further discussed in Chapter 8 under proposed future work.

6.6.1. Limitations of the study

The results of the current study may have been affected by inherent limitations in conducting interviews such as the respondent's skill at self observation (Armstrong et al., 2002). Bowen (2008) suggests another limitation of the interview approach where data saturation is assumed, but without any explanation of what it means and how it occurred. Recognising the saturation point presents a challenge to qualitative research. In the current study however, no new themes emerged when the number of interviews reached eight suggesting data saturation and indicates that the sample size was probably adequate. Dowding and Johnson (2008) provide insight on the number of participants required to evaluate a web-site from a study that involved a rigorous usability testing methodology. Their study shows that six to nine participants were needed to evaluate, despite the general agreement in the literature that suggests that four to six is appropriate.

Walkthroughs followed by in-depth interviews with the practitioners helped to identify strengths and weaknesses of the tool. However, this approach can only provide limited information pertinent to the evaluated tool and may have biases (Rosenbaum, 1989; Armstrong et al., 2002). For instance, Rosenbaum (1989) reports that, interviews may not yield all usability issues due to the fact that the interviewees are not always qualified to judge every aspect of a product or a process. Although interviewing eight experienced practitioners reduced such shortcomings, further scrutiny of the individual methods, tools and techniques may be necessary particularly to understand their performance in the industrial setting.

Although 19 practitioners expressed an interest in taking part in further studies, three had to be omitted as they were from overseas. In addition, although 38% of the practitioners reported that they were lecturers, they also categorised themselves under other occupations. Furthermore, all of the practitioners considered managing ergonomics projects as one of their job responsibilities. Therefore, they can be considered as active in industry. This reduces the bias that can occur due to a high proportion of one participant group with low experience in the industry. Williams and Haslam (2006) report that overall, both practitioners and academics demonstrated confidence in the competencies expected from an ergonomics professional as listed in the international ergonomics association (IEA) website. In addition, in a survey of professional ergonomists, 8.8% categorised themselves as educators indicating that educators also take part in industrial projects as practitioners (Dempsey et al., 2005). These studies minimise concerns about the relatively high proportion of academics in the sample.

6.7. Summary

In-depth interviews were conducted using a walkthrough approach with eight practitioners, all of whom appreciated the tool and its features. Half said that the design tool would help them collaborate/communicate with other stakeholders in the design process and guide them through it. All of the practitioners appreciated the features to help ‘prioritise user requirements’, ‘identify design solutions’ and ‘record knowledge for future use’. They also identified limitations of the tool and its features. Lack of guidance on using the tool itself, and the time needed to go through the process were the major limitations identified by the majority of the participants. All suggested including clear guidance as an important part of future development of the tool. The majority also suggested automation as a strategy to reduce the time needed to go through the process. Further investigation in the industrial setting is now necessary.

7. Practitioner case studies

7.1. Introduction

It is essential to evaluate the design tool in detail to understand more about its potential, feasibility, usability and to identify directions for future development. Previous research suggests approaches such as review of published cases and peer review for in-depth evaluation of tools and techniques similar to the proposed quality function deployment (QFD)-based design tool (e.g. Haines et al., 2002). Case studies also can provide a basis for in-depth review, and are carried out in action research to help evaluate tools and techniques and to identify paths for future development (Rubin, 1994; Creswell, 2007; Saunders et al., 2007). The design tool (and the guidance material) was initially developed based on an extensive review of the related literature (refer Chapter 4). It was subsequently subjected to a peer review process and an initial evaluation (refer Chapters 5 and 6) to ascertain its content and to determine its feasibility with respect to current practices. It was also important to evaluate its strengths and weaknesses in the field setting (refer Chapter 1: Objective 4). A case study approach was therefore adopted to evaluate the design tool and guidance material more rigorously in the field setting as part of design practice. The sub-objectives were:

- To evaluate the usability of the design tool and guidance material;
- To understand the capabilities and limitations;
- To identify directions for future development.

7.2. Sampling

Practitioners were asked both in the questionnaire survey and during the interviews whether they would like the opportunity to understand the design tool further and use it (with support) on one of their current or future projects. Those that agreed to participate were asked to select a work task of their choice that required design solutions in terms of equipment, facilities, procedures and training to help reduce workplace risk factors for developing musculoskeletal disorders (MSDs) among the workers. These case studies were carried out by the practitioners at the sites where they were handling the projects. Participation in the case studies was voluntary and informed consent (Appendix 7.1 and Appendix 3.2) was obtained. The Loughborough University ethical guidelines (Loughborough University, 2003) for studies involving human participants were observed.

7.3. Data collection

After initial communications with the practitioners to ascertain their involvement in the case studies, they were contacted by email to provide them with further details about the research. A web link to the design tool and its guidance material (refer Section 4.6) was included in the email (www-staff.lboro.ac.uk/~huhkgp). They were instructed to use either the guidance material or any other methods they were familiar with to identify the risks and obtain user requirements pertinent to the case study project that they selected. They were asked to document the tools and techniques that they used to identify these risks and requirements. They were also asked to either use the developed Microsoft® Excel-based tool or any other method they were familiar with to prioritise the risks and user requirements and to document the process. They were then invited to participate in a session to go through the features of the design tool in detail.

Prior to the session, the practitioners were asked to have the list of prioritised risks and user requirements available for use. In addition, they were asked to have available any background information (printed and electronic) pertinent to the case study project (e.g. the work task, task elements, number of workers engaged in the work task and worker exposure time to the work task, etc.) and any documentation that may be useful for the session (e.g. relevant risk assessment data, photographs, diagrams and measurements etc.). They were also instructed to arrange a computer with internet facilities and were informed to set aside 2-3 hours. Practitioners were briefed about the objectives of the case study and informed consent was obtained. It was expected that only a brief introduction to the design tool would be necessary as they had prior knowledge of it from the interviews and by having access to it. They were then asked to browse through the guidance tool for 10 minutes to help familiarise themselves with the approach and were encouraged to ask any questions.

During the case study session, the practitioners were asked to select two requirements for design from the prioritised list that they had already established and to verbalise the rationale behind their selection. Taking the first requirement for design, they were asked to use the appropriate features of the tool to identify acceptable solutions, present them using the developed QFD-based matrix and then to record the knowledge using the solutions database. They were allowed to use any documentation such as photographs, task information, design data and so on required to facilitate this process. The same procedure was followed for the second requirement for design. The process was observed using an observer-participant approach whereby the researcher was present during the entire session, and it was made clear to the practitioners that they could ask questions at any time (Merriam, 1988). Observations were recorded as fieldnotes, and video recording was used as a memory aid in this process. A Panasonic® SDR 40GB high-definition digital (HDD) camcorder was directed at the computer screen that the practitioner was working on to video record the process. Practitioners were also informed that they could take breaks at any time. After 1.5 to 2 hours, the session was brought to a close and semi-structured interviews were conducted with the practitioners.

The websites of the companies where the case study projects were carried out were browsed before meeting the practitioners in order to obtain relevant background information. Company profiles, number of established facilities and the number of employees were recorded. In addition, details of the case study projects were collected through email and verbal communications with the practitioners before meeting them. They also provided information about the case study projects at the beginning of the meetings to help further understand the work tasks. During the case study sessions, observations were carried out using a set protocol (Appendix 7.2) for each of the two prioritised requirements for design. A summary of the observations protocol is given in Table 7.1. Both descriptive and researcher-reflective data based on observations were recorded when taking fieldnotes. Data that could be retrieved from the video recordings were not noted during the case study session.

Post-task semi-structured interviews were also carried out on site using an interview guide (Appendix 7.3). Probing questions were also asked when necessary to help shed light on the issues under discussion. During the interviews, the practitioners' opinion on the capabilities and limitations of the features of the design tool, and elements that needed to be added, omitted or modified to enhance its use as a tool to help practitioners reduce work-related MSDs were elicited. Ratings on the performance of the features of the design tool (except for identifying risks and obtaining user requirements) were also collected using a Likert type scale (1= very poor to 7= excellent), similar to that used in the practitioner survey (refer Chapter 5). The performance of the design tool as an integrated approach was also recorded using a similar scale. Finally, practitioners were asked to rate its usefulness using a Likert type scale (1= not useful to 7= highly useful). For the purpose of data collection, the features of the design tool, ‘identifying design solutions’ and ‘selecting acceptable solutions’ were considered together, and were tagged ‘identifying acceptable solutions’ because these activities in the process were carried out together. The remaining features of the design tool were kept unchanged. The interviews were audio-recorded using an Olympus® VN-2100PC digital voice recorder.

Table 7.1. Summary of the observations protocol

Section	Recorded information
Identifying acceptable solutions	Selected user requirement; rationale behind the selection; start-time for identifying acceptable solutions; time completed; solutions obtained (solution, corresponding design principle, solution type- whether it is for equipment, facility, procedure or training); questions asked; difficulties encountered; documents used
Presentation of risks, requirements and solutions	Start-time for filling in the QFD-based matrix; time completed; questions asked; difficulties encountered; documents used
Recording knowledge for future use	Start-time for filling in information on the database; time completed; questions asked; difficulties encountered; documents used

At the end of the interviews, relevant documents, photographs and other information (electronic and printed) were requested from the practitioners to fully understand and support description of the chosen case study projects. Information that could not be obtained at the session was sent by email. In order to ensure the relevant documents were obtained, a checklist was used (Appendix 7.4).

7.4. Analysis

Information from the company web sites, email and verbal communications with the practitioners, documents, photographs and other relevant material made available by the practitioners were used to describe the bounded systems (Blaxter et al., 2006). Photographs and other material such as hierarchical task analysis (HTA) results were used whenever possible to help illustrate the work tasks and the task elements. Information that potentially revealed the identity of participants or the participating organisations were hidden.

Fieldnotes, video recorded data and relevant documents collected were used to elaborate the procedures followed by the practitioners during the case study sessions. Then, the tools and techniques used by the practitioners to ‘identify risks and obtain user requirements’ were noted. After that, prioritised risks and user requirements were tabulated. Next, the design solutions that were identified by the practitioners were listed with the corresponding design principles and solution types.

Content analysis (Blaxter et al., 2006) was performed using the field notes and video recordings to assess the usability, capabilities, limitations and directions for future development of the design tool. For example, the instances where questions asked by the practitioners and difficulties they encountered (using both descriptive and researcher-reflective data) while using the guidance material were used to determine usability issues and limitations. These were supported by the themes extracted from the interviews with the practitioners. Techniques described by Ryan and Bernard (2003) were used to identify themes and they were classified according to the features of the design tool. As conducted in the previous studies, frequencies of similar themes across the case studies were used to ascertain the importance of the themes (Glaser and Straus, 1967; Erlandson et al., 1993; Boeije, 2002; Creswell, 2007).

Finally, the performance ratings obtained during the interviews for the features of the design tool were graphically presented. Performance and the usefulness of the design tool were also determined.

7.5. Results

7.5.1. Participants

Three practitioners agreed to participate in the case studies. Two of them took part in the practitioner interview study (refer Chapter 6) and the other only took part in the practitioner survey (refer Chapter 5). All worked in large multi-national organisations: a world leader in tyre manufacturing and retreading (a female ergonomist), a world leader in aircraft manufacturing (a female industrial engineer) and a prominent poly vinyl chloride (PVC) product manufacturer (a male occupational health technician).

Two of the practitioners (ergonomist and the occupational health technician) took part in the entire case study. However, the industrial engineer was not able to take part in the case study session and therefore, participated in the face-to-face semi-structured interview only.

7.5.2. The case study projects

The work tasks for the case studies were selected by the practitioners based on their company requirements. These presented potential musculoskeletal concerns and required potential design improvements. Thus, the case studies were amalgamated with the company directives to review the work tasks and improve them.

Case study 1: Stitching operation study

The first case study involved a tyre retreading facility and was concerned with helping to reduce the potential workplace risk factors for MSDs in repairing beads and punctures in tyres. This facility is one of approximately 70 manufacturing facilities of the company spread across the globe that employed around 200,000 people. Permission was granted by senior managers to conduct the case study session. The company also made available data obtained from the workers and granted permission to publish the study results withholding the company and participant identities.

The work task known as the stitching operation in the industry had seven task elements as identified by the practitioner (Table 7.2) and involves manual handling and the use of hand tools to repair beads and punctures. The objective of the practitioner was to reduce the effort required for manual work to repair the beads and punctures (Figure 7.1), as manual lifting, pushing, pulling and applying pressure were required to perform this task. In addition, this work task in particular required the use of a set of hand tools known as ‘stitchers’ (Figure 7.2). The stitchers used in this manufacturing facility were around forty years old. They were originally made of steel and were without any soft grips for the handles. Some stitchers had even been improvised by the workers (users) themselves, by wrapping the handle with rubber to make them more user-friendly. The grips were repaired by the workers themselves from time to time, to compensate for the wear due to continuous use. The stitching operation can be categorised as a ‘stationary workstation and a cyclic work task’. Twelve workers from five different teams within the company were employed to carry out this work task.

Table 7.2. Task elements of the stitching operation

Task element	Description
Manoeuvring the trolley	Pushing and pulling the trolleys that hold the casings to be loaded to the workstation. A trolley holds 6 casings. Each casing can weigh up to 70 kg. Rotate the trolley on the spot after finishing three casings at the workstation to facilitate attaching to the hoist.

Task element	Description
Loading the casing	Using the hoist to assist loading of the casings from the trolley to the workstation and mounting it on rollers.
Extruding hot rubber	Using a hand held extruder gun to fill hot rubber into damaged areas of casings.
Repairing beads and punctures	Use rubber strips to build up material and use hand tools (stitchers) to press it against the inside wall of the casing to remove air trapped between the rubber strip and the casing.
Rotating the casing	Manually remove the casing from the rollers of the workstation, rotate and remount it on the rollers to access the other side of the casing.
Unloading the casing	Manually unloading the casings from the workstations
Loading to trolleys	Manually loading the casings to the trolleys to be sent to the next workstation.

Figure 7.1. A worker repairing beads and punctures

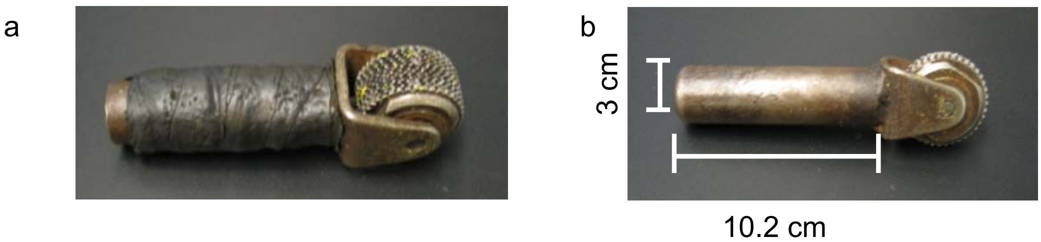


Figure 7.2. Wide stitcher (a) with the rubber wrapping around the handle and narrow stitcher (b) without the rubber wrapping around the handle

Case study 2: Pipe installation study

The second case study was concerned with improving a component of an aircraft to reduce work-related MSDs among the workers in an aircraft manufacturing facility. This facility was one of approximately 12 such facilities spread across Europe that employed around 52,000 people. Unfortunately, permission was not granted to conduct the actual case study session due to reasons of confidentiality. Nevertheless, permission was granted for a discussion regarding the implementation of the design tool with the practitioner. Permission was also granted to publish any findings, provided they were made anonymous.

The studied work task involved the installation of pipe work components in a fixed structure. This requires gaining access through an oval aperture with dimensions of 457 by 254 mm followed by a side bend of the body and arm extension. This posture is maintained for up to two minutes, together with fine manipulation of the hands and arms to reach the location and secure components in the fixed structure using bolts. According to the practitioner, the job can be categorised as a 'stationary workstation and a cyclic work task' and eight workers are employed to perform it. Unfortunately, the company did not give consent to providing photographic evidence of the work task, but a comprehensive HTA diagram was provided. A section of it is shown in Appendix 7.5.

Case study 3: Material loading study

The third and final case study was carried out to help improve the material loading process in a PVC product manufacturing facility to reduce work-related MSDs among the material loaders. This facility is one of approximately 30 manufacturing facilities of the company spread across the world that employs over 4,000 people in all. Permission was granted by the senior managers to publish the results of the implementation as long as the company or participant identities were not revealed. The author was also given access to the data that were collected from the workers.

The studied work task involved transferring raw material in a powdered form that arrives from the premix in a room above, down a vertical metal tube (feeder) to a mixing and processing machine called the banbury. Raw material flows continuously through the feeder, and is collected in boxes that are positioned on a small roller platform located below the feeder. An empty material box weighs 10 kg, and is 50 kg when filled with raw material. A box once full is manually pushed or pulled 5 meters along a platform, which does not have rollers, towards the banbury. It is then manually turned 90^0 and pushed a further 1.5 m on a roller conveyor to the hopper of the banbury. After that, the box is tipped over the 12 cm ledge of the hopper into the banbury and the empty box is dragged back to the feeder. When a box is full, it is replaced with an empty box positioning it below the feeder to collect raw material. The empty boxes are held on a surface equal in height and parallel to the platform ready to be placed below the material feeder tube. Part of the apparatus for the process is shown in Figure 7.3.

Colour packs are also added to the banbury through the hopper. These weigh 0.5 kg to 10 kg and are collected from a trolley that is located between the two banbury machines, approximately 6 m to 8 m away from each banbury. The operators manually lift and carry colour packs from the trolley to the banbury. When full, the colour packs are 1.5 m from the floor level and when nearly empty, they are 70 cm from the floor level. When the colour pack trolley is empty, it is required to be returned and another load is required to be collected manually from a storage area 25 m across a metal plated floor with bump ridging. When full, the trolley contains a maximum of 800 kg of colour packs in addition to the weight of the empty trolley. This is usually a task carried out by a single operator, but additional operators get involved if required. Two boxes full of raw material and one colour pack are emptied into the banbury hopper approximately every 5 minutes.

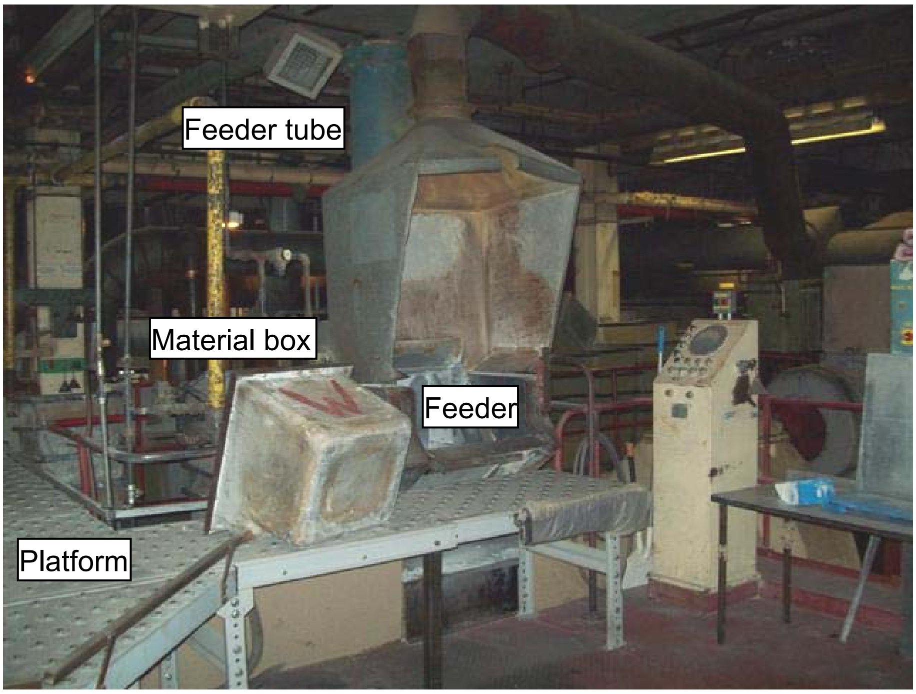


Figure 7.3. Banbury: a raw material box and part of the platform that the boxes have to be dragged along

Scrap PVC is also fed to the banbury in batches of 80 kg (2 x 40 kg) when it has accumulated. Scrap is packed into bags and placed in bins. A hoist is used to lift the bags from the bins to minimise manual handling. According to the occupational health technician, the job can be categorised as a ‘stationary workstation and a cyclic work task’. However, from time to time colour packs need to be brought to the workstation and this task can be considered a ‘variable environment and a cyclic work task’.

7.5.3. Identifying risks and obtaining user requirements

In the stitching operation study, the practitioner herself recruited all the rubber repair workers from five separate teams (n= 12). The semi-structured interview guide linked to the guidance material (Appendix 3.3) of the design tool was used to identify user requirements, and audio recorded face-to-face interviews with the workers were conducted. Direct observations supplemented by video recording, the Nordic musculoskeletal questionnaire (NMQ) (Appendix 7.6.a) and whole body discomfort (WBD) (Appendix 7.7.a) information and rapid entire body assessment (REBA) risk levels (Appendix 7.8) were also used by the practitioner to help verify the user identified risks and user requirements. Issues related to the grips of the stitchers were identified by the majority of the workers. Period prevalence was high in the hands, fingers, shoulders and the lower back while point prevalence was high in the wrists, hands and the fingers. Right shoulder, right hand and fingers showed the highest discomfort after one hour of work. Repairing beads and punctures showed the highest REBA risk levels (high/very high).

In the pipe installation study, a focus group had been conducted to obtain design needs to reduce the risks for MSDs. This involved employees with experience of the work task (n= 4); safety engineers responsible for the work task (n= 2); shop support engineers (n= 2); a team co-ordinator with experience in the work task and a planning engineer. The focus group session was guided by the practitioner that participated in the study. Recruitment was based on the information developed as part of an HTA exercise and the company directive. Although employees from other areas related to the work task were asked to participate in the focus group session, based on shifts and willingness, the number was restricted to 11 individuals including the practitioner. Two sections (i.e. ‘awareness of MSDs’ and ‘user requirements’) of the interview guide available in the design tool (Appendix 3.3) were used to obtain user requirements. In addition, WBD analysis (Appendix 7.7.b) for the piping workers was carried out to support the findings from the focus group session. Having to adopt awkward postures to reach working area was identified as one of the needs. The lower back showed high discomfort at the beginning of the work task. The REBA risk level calculated by the practitioner for the work task was identified as very high (score= 10).

In the material loading study, the risks and user requirements were elicited from workers (n= 6) that were regularly involved in the work task (banbury operators). The occupational health technician used the interview guide (Appendix 3.3) made available in the design tool. Direct observations, the NMQ (Appendix 7.6.b) and WBD (Appendix 7.7.c) information were also used by him to help verify the risks and user requirements and to add details to the requirements for design. Mechanical aids to lift and feed the premix were identified by the majority of the workers as a requirement. The elbows and lower back showed high period prevalence of musculoskeletal symptoms. The elbows also showed high point prevalence. In addition, the lower back showed high discomfort both at the beginning of the work task and after one hour of work.

7.5.4. Prioritising risks and user requirements

In the stitching operation study, the practitioner had extracted themes from the worker interviews to identify risks and requirements. The Microsoft® Excel-based tool developed to facilitate the constant comparative method and frequency analysis to identify frequently occurring themes (Appendix 4.1. and also refer Section 4.5.2) was used to prioritise themes. Ten risks with requirements for design were identified by the workers in this study.

In the pipe installation study, the themes that came up regularly and were agreed by a majority of the participants during the focus group session were given a high priority. The Microsoft® Excel-based tool this time was not used to prioritise the user requirements. Constant comparative method followed by frequency analysis was used to identify and prioritise the themes, but the practitioner used a pen and paper to note down themes since it was thought to be more convenient during the focus group session. Three user requirements were identified.

In the material loading study, the Microsoft® Excel-based tool was used by the practitioner to prioritise the risks and user requirements. The researcher provided help to obtain the prioritised list of risks and suggested requirements for design after the practitioner had entered the themes in the tool. Altogether, nine user requirements were identified by the six workers that were interviewed by this practitioner.

It is interesting that some of the requirements identified by the workers were not directly physical risk factors for developing work-related MSDs. For instance, 17% of the stitchers expressed that the 'handle gets very hot as they are made of metal' and 17% of the banbury operators mentioned the need to 'minimise fumes from the banbury'. The prioritised lists of user identified risks and requirements identified in the three case studies are shown in Table 7.3. As a result of using a focus group technique, for the pipe installation study, the practitioner was not able to quantify the number of workers expressing concern.

Table 7.3. Prioritised user identified risks and requirements pertinent to stitching operation, pipe installation and material loading studies (within brackets, % of workers expressing concern)

Stitching operation study (n= 12)	Pipe installation study (n= 10)	Material loading study (n= 6)
Need to be able to grip the handle firmly as a lot of weight needs to be put on to the handle [84]	Need to adopt awkward posture to reach working area	Provide mechanical lifting equipment to push and tip/ feed the premix [83]
Reduce the effort needed [58]	Need to climb through restricted opening	Reduce the need to reach the bottom of the bin [67]
Tools wear quickly [58]	No clear view of working area	Provide training on risk free use of the bins [50]
Need a suitable grip for comfort [58]		Reduce the dust generated due to the premix [33]
Repetitive nature of the job [58]		Mechanise the banbury table and the tilt mechanism [33]
Make the tools lighter [50]		Reduce the noise levels in the banbury [17]
Tools are old and worn [42]		Minimise fumes from the banbury [17]
Ability to personalise the tools [42]		Make the floor levels even to reduce aches and pains in the ankles and feet [17]

Stitching operation study (n= 12)	Pipe installation study (n= 10)	Material loading study (n= 6)
Difficult (awkward posture) when working inside the casing [33]		Provide good lighting [17]
Handle gets very hot as they are made of metal [17]		

7.5.5. Identifying acceptable solutions

For the stitching operation study, two requirements for design were selected by the practitioner (ergonomist) to be deployed in the developed QFD-based matrix. These were the ‘need for a suitable grip for comfort’ and the ‘ability to personalise the tools’. The ergonomist randomly selected the first design requirement and then selected the second requirement as it was related to the first. No documents were used apart from the design tool (and guidance material) during the entire session. Eight different solutions were identified by this practitioner for the two requirements during the case study session. Using the design principles as an aid to brainstorming, it took 30 minutes for the practitioner to identify solutions for the two requirements. The researcher had to initially remind the practitioner to go through the design principles to identify solutions, but after that the procedure was followed without any interruption. Table 7.4 lists the identified solutions, the relevant design principles used to identify the respective solutions and the solution types. The risks and user requirements, solutions, relationships and interactions were entered in the developed QFD-based matrix (Appendix 7.9). The relevant observations and related standards, guidelines or regulations were not filled as the practitioner did not have access to this information at the time, but notes were entered in the matrix as a reminder to enter the details later. The practitioner also determined correlations between the solutions to complete the interactions matrix with researcher assistance. The practitioner took 20 minutes in total to enter this design information into the matrix.

Table 7.4. Identified solutions during the stitching operation case study session

Solution	Design principle*	Solution type
Different tooling for different job requirements	1	Equipment
Changing the grip on the tool, one standard tool with different grip options	7	Equipment

Solution	Design principle*	Solution type
Reduce the weight of the tool and using lighter materials	2	Equipment
Fit to the individual hand	3	Equipment
Size and shape of the tool/ handle	3	Equipment
Make tool universal for all operators	8	Equipment
Use of a hollow structure to reduce weight	9	Equipment
Use of composite materials to reduce weight and increase strength	2	Equipment

* Note: see Appendix 4.2 for the list of design principles

In the pipe installation study, the practitioner together with the same participants that had taken part in the focus group had already discussed the design principles in a separate focus group session. They identified six design solutions to the three requirements for design (i.e. need to adopt awkward posture to reach working area, need to climb through restricted opening and no clear view of working area) using the design principles presented in the tool (Table 7.5). According to the practitioner, they took approximately one hour to come up with the six solutions. They also referred to a document called ‘manufacturing instructions’ that describes in detail the job procedure to help understand the work process comprehensively. Interestingly, the risks and user requirements, corresponding observations, solutions and relationships were all included in their QFD-based matrix. It is shown in Appendix 7.10. However, they did not complete the interactions between the solutions. After identifying the solutions, the participants decided the feasibility of them and assigned colours according to the coding system given in the guidance material. Since the interactions were not completed, feasibility had been decided based on the ability of the solutions to be implemented. Furthermore, the practitioner once again had not listed any standards, guidelines or regulations due to unavailability and company policy.

Table 7.5. Identified solutions during the pipe installation case study session

Solution	Design principle*	Solution type
Install some internal features before the wing-box is closed	13	Facility
Change shape of opening to reduce sharp edges	3	Other
Find alternative means of access	4	Other
Develop set sequence of moves to enable common approach and opportunity to train in safe facility	1	Training
Do as much pre-work as possible before entering working area	6	Equipment
Explore alternative fixing methods or tools	22	Equipment

* Note: see Appendix 4.2 for the list of design principles

In the material loading study, the case study session was attended by the company physiotherapist in addition to the practitioner (the occupational health technician). Solutions were identified for two of the user requirements with the assistance of the design principles in the design tool. The two user requirements at the top of the priority list (provide mechanical lifting equipment to push and tip/feed the premix' and 'reduce the need to reach the bottom of the bin') were chosen for the focus of the session. Overall, eight solutions were identified for the two user requirements (4 solutions for each of the requirements). The practitioners systematically worked through one requirement for design at a time to identify solutions. It took 65 minutes to identify solutions and enter design information in the matrix for the two chosen requirements. The practitioners decided not to enter potentially infeasible solutions that were suggested in the matrix. Table 7.6 shows the solutions and the design principles used for the two user requirements to help reduce work-related MSDs. After identifying the solutions, brief comments were entered in the observations column and interactions between the solutions were decided. The standards, guidelines and regulations section was again not completed due to the unavailability of relevant information, but possible sources of information on standards, guidelines and regulations were noted. It is similar shown in Appendix 7.11.

Table 7.6. Identified solutions during the material loading case study session

Solution	Design principle*	Solution type
Automatically timed feeding tube from the premix to the banbury eliminating the repetitive nature of the work over a length of a shift	6	Equipment
Installing a mechanical tilt mechanism to help the premix into the banbury via the bucket	19	Equipment
Use of hydraulics to assist in the lifting of the banbury buckets by use of button or lever	17	Procedure
Packing the premix using a vacuum-pack process to reduce the amount of manual handling	20	Procedure
Change in dimensions of the bucket in order to reach the bottom with no strain on the lower back or abdominals	4	Equipment
Install a tilting mechanism to make reaching into the bucket easier with no strain on body parts	3	Equipment
Installing a spring loaded mechanism into the bins to rise and drop depending on the weight	10	Procedure
Utilisation of a vacuum mechanism to lift the material from the bins	17	Equipment

* Note: see Appendix 4.2 for the list of design principles

7.5.6. Presentation of risks and requirements, and solutions

In the stitching operation study, the practitioner used the developed QFD-based matrix to present design information (Appendix 7.9), and was inclined to eliminate solutions that were thought to be technically infeasible while identifying solutions. Thus, there were no solutions in the matrix that were coded in RED. The final matrix therefore looked similar to the one that was completed during the previous step that identified acceptable solutions. The practitioner took 12 minutes to colour code the solutions. In the pipe installation study also, the matrix that was completed in the previous phase (identifying acceptable solutions) was used and solutions colour coded to present design information (Appendix 7.10). The practitioner had decided to retain the solution coded as unfeasible (RED) in the final matrix. In the material loading study, once again the matrix from the previous phase was used to present design information (Appendix 7.11). Only solutions coded in GREEN and AMBER were present since the practitioner did not identify any technically infeasible (RED) solutions during the identification process. Colour coding took 5 minutes of their time.

7.5.7. Recording knowledge in a solutions database for future use

In the stitching operation study, the practitioner copied the design requirements and the solutions to the database. Then, the drop-down menus were used to fill in the 'solution type', 'addressed risk' and design principles for each of the requirements and solutions. Force (load) and equipment were chosen as the 'addressed risk' and 'solution type' for all of the solutions. Applicable standards, guidelines and regulations were left to be completed later as such information was not available for the case study session. Notes were also left to remind the practitioner to enter cost, benefits and other necessary information later. It took 10 minutes for the practitioner to enter the required data into the database. Part of the completed database is shown in Appendix 7.12.

In the pipe installation study, all of the solutions addressed the MSD risk due to awkward postures. Solutions were pertinent to equipment, facilities and training, but there were two solutions where the solution type was identified as 'other'. These solutions were to redesign the component in which the pipes are installed, in order to reduce awkward posture. Although standards, guidelines and regulations were not listed in the database, other relevant information had been entered relevant to one of the solutions. The practitioner reported that they had completed the solutions database before completing the developed QFD matrix. They used the solutions database in the process of identifying acceptable solutions as design principles could be accessed easily using the dropdown menus of the database. Part of the completed database is shown in Appendix 7.13.

In the material loading study, the occupational health technician entered data into the database. Practitioners agreed on the solution type and the risk to be addressed through discussion. The drop-down menus were used to select the 'solution type' and 'addressed risk'. All the solution types were determined as either equipment or procedure and the 'addressed risk' was decided as either force (load) or posture related. Other design information was copied from the QFD-based matrix and pasted into the database. Notes were entered to remind them to include relevant standards, guidelines and regulations data at a later date. It took 15 minutes for the practitioners to complete the database. Part of the completed database is shown Appendix 7.14.

7.5.8. Critique of the design tool (and guidance material)

The observation data (from two of the case studies) and the semi-structured interviews with the practitioners were used to evaluate the tool according to the objectives (refer Section 7.1).

All of the practitioners were positive about the design tool (and guidance material). They indicated that it could be used to manage design information and visualise an elaborate picture of the MSD issues and possible solutions before pursuing them, thus helping to share design information. However, they also indicated that the entire process was time consuming and that perhaps many of the procedures could be automated in order to reduce the time requirement. For example, the practitioner in the material loading study stated:

> *It is good to use it* [the design tool]*, to see how good it is. It is a useful tool. For me, it proved to be effective. Through this process, it opened my eyes to the problems in there and think that QFD might kind of, minimise MSDs, that is occupational health, my area of work. This kind of programme really appeals to me. This can identify issues and present it to the managers. It starts with identifying themes, it goes to prioritising themes to solutions and goes to QFD, comparing solutions, getting acceptable solutions and proceed to presenting. I think you've got a very good tool there. It is open to other companies, other sectors as well. I would definitely use the approach in the company. I would think of developing it myself to be more effective in my company. How I could develop it, I am not sure. I don't know whether it is possible, may be a level where you do not have to type so much, where many things are done for you automatically. It is probably for the future.*
>
> Occupational health technician: Material loading study

Another salient issue mentioned by all three practitioners with respect to the entire design tool was the requirement for a simple set of guidelines to help them use the tools and techniques listed in the guidance material. For example:

> *Easy set of guidelines. Initially I was puzzled about what I need to do. If you are not IT literate, then it would be very hard to work with it. Even if a lot of people work with documents, they might find it difficult.*
>
> Occupational health technician: Material loading study

Although strengths and weaknesses of the guidance material for understanding risks and design requirements were not specifically assessed, the practitioner in the pipe installation study (industrial engineer) mentioned that the interview guide was too long for industry. This practitioner further stated that 'awareness of MSDs' and 'user requirements' sections in the interview guide (Appendix 3.3) were mainly used by her with success. The industrial engineer also said that the workers responded more to the question on what they dislike about the work task than other questions. In addition, this practitioner mentioned that the WBD analysis and REBA were useful to verify the risks identified by the workers.

With regard to prioritising the risks and user requirements using the Microsoft® Excel-based tool, themes were identified for usability, capability, limitations and directions for future development. These are summarised in Table 7.7.

Table 7.7. Evaluation of the tool for 'prioritising risks and user requirements' (within brackets, the number of practitioners expressing views)

Usability	Capabilities	Limitations	Directions for future development
Difficult to browse through the themes [1]	Provides a structured way to prioritise themes [2]	Not enough guidelines [2]	Provide clear and simple guidelines [3]
Having to interpret and type in themes several times [1]	Simple and effective method to prioritise [2]	Might miss risks and requirements that may not be identified by workers [1]	Format the Microsoft® Excel sheets for easy scrolling and visualisation [1]
Difficult when used for the first time [1]			Reduce having to retype information [1]

The ergonomist from the stitching operation study mentioned that it was difficult to browse through the themes. She further stated that this was due to the fact that the guidelines that were given at the top of the spreadsheet in frozen cells occupied the majority of the workspace. In the pipe installation study, the industrial engineer's concern was the time needed to interpret and type the themes, and the practical difficulty of this was acknowledged. However, a possible improvement was suggested:

> *My concern is the time element. Having to interpret and type everything in and I don't know whether there is an electronic way of drawing out information. I understand people use different language and express things differently. Reduce the number of times the same information has to be typed in. Have only one level of data entry and obtain the priorities based on the first level of information since you have the responses to the interview questions if you need more information.*
>
> Industrial engineer: Pipe installation study

The occupational health technician in the material loading study mentioned that prioritising risks and user requirements became easier after obtaining direct instructions from the researcher (author) signifying the inadequacy of the written guidance and the importance of training.

> *Obviously when I used it for the first time it was a bit harder. When I went through the instructions, it was a bit overwhelming, but after I got face to face instructions from you, it became quite easy. When I do it for the next time, I could do it easily. It is really simple. I have used it once, I would use it again.*
>
> Occupational health technician: Material loading study

Even though the practitioners identified that this structured approach is simple and effective, the occupational health technician mentioned that the 'user identified risks and requirements' should not be relied on. He was concerned that there might be workplace risk factors that were difficult for the workers to identify. This practitioner recognised the importance of other information, for example, observations of the work task, and using this data to supplement any user identified risks and requirements.

> *When many workers say the same thing, you know that there is something wrong with that. So it is very good to identifying a problem. Although only a*

> *few mentions, there might be a more dangerous task, which is less obvious to many of the workers. This might be a limitation, but practitioner observations and other methods can help in this.*
>
> Occupational health technician: Material loading study

All three practitioners identified the requirement for clear and simple guidance as a priority for future development of the tool. The ergonomist in the stitching operation study further stated that there were no guidelines to stop practitioners from entering a theme more than once: workers may mention the same issue multiple times. It was also reported that the Microsoft® Excel sheet needs to be formatted for easy scrolling and visualisation of the themes. In addition, the industrial engineer from the pipe installation study suggested reducing the repetitive operations required in entry and refining of the themes.

> *Reduce the number of times the same information has to be typed in. Have only one level of data entry and obtain the priorities based on the first level of information since you have the responses to the interview questions if you need more information.*
>
> Industrial engineer: Pipe installation study

Evaluation of the parts of the design tool concerned with identifying design solutions and selecting acceptable solutions were carried out together. Thus, the design principles and the QFD matrix-based tool were taken together for evaluation. These are summarised in Table 7.8.

Table 7.8. Evaluation of 'identifying acceptable solutions' (within brackets, the number of practitioners expressing views)

Usability	Capabilities	Limitations	Directions for future development
Difficult to format the MS Excel matrix template [3]	Design principles are very useful and helpful to identify a variety of alternative solutions [3]	Quite overwhelming when the QFD-based matrix is initially seen [3]	Need simple guidelines to help practitioners in each stage integrated to the matrix [3]

Usability	Capabilities	Limitations	Directions for future development
Having to create and copy text boxes in the triangular interactions matrix [3]	The QFD-based matrix can be used to enter all necessary information [3]	An individual may not be able to come up with solutions [1]	Explanation on positive and negative interactions need to be provided [3]
Need to keep several windows open and swap between them [2]	Good to have observations, standards, guidelines and regulations information in the matrix [3]	Having too many solutions might make it difficult to decide which ones to use [1]	Facilitate formatting the Excel template [3]
Unable to refer to the example easily [1]	The matrix helps compare different solutions [3]	Takes time to go through the list of design principles [1]	Integrate an example to the QFD template [2]
Design principles are easy to understand and use [1]	Colour coding system for the solutions is intuitive [3]		Good to have links to find standards, guidelines and regulations [2]
Translation of information across the matrix is not a problem [1]			Provide reference to TRIZ principles [1]

Both the ergonomist and the industrial engineer found changing the Microsoft® Excel template (e.g. font size; triangular interactions matrix) was particularly cumbersome to keep the matrix to a manageable size and to match the size of the triangular matrix to the rest of the QFD-based matrix. This was not found to be a problem by the occupational health technician, although it is acknowledged someone inexperienced with Microsoft® Office tools may find it difficult. The list of design principles was identified as an important and a useful element of the design tool and valued by all three practitioners. They reported that the tool makes it possible to filter feasible and practical design solutions from a number of alternative possible solutions. For example:

> *It* [the set of design principles] *is a good guide to extracting design solutions. Can filter through loads of design solutions to select the feasible or practical ones. Otherwise, you might miss something that is important.*
>
> Ergonomist: Stitching operation study

> *It* [the set of design principles] *is very good. This is probably the best feature of the tool and it is novel. We were able to look at each description and discuss in detail what does it mean. It gives descriptions of what they mean and it helped. To me, it helped focus. Normally if we see a heavy object, we choose a mechanical aid, but there are other things we can do like split it, which is one of the principles.*
>
> Industrial engineer: Pipe installation study

The occupational health technician reported that it is easy to understand and use the design principles. Nevertheless, the ergonomist cautioned that 'having too many solutions might make it difficult to decide which ones to use'. The industrial engineer stated that although it took time for the group to go through each item of the design principles they admitted that once they are familiar with the list, the time requirement would be less. In addition, the inclusion of relevant observations, standards, guidelines and regulations information in the matrix was acknowledged by all of the practitioners. For example, the industrial engineer mentioned that:

> *It is important to have standards and guidelines in the matrix. If you have access to the related standards and guidelines, it adds weight to the argument. It is a case of knowing what they are.*
>
> Industrial engineer: Pipe installation study

All practitioners identified the ability of the QFD-based matrix to help compare solutions as an important feature:

> *It gets you thinking about, when you are seeing, um… I don't know… five solutions you think is good at first. The QFD matrix lets you look at it and cross reference it to a different solution. As you get to the end of the matrix, you see a lot of negative aspects of the solutions. So it is kind of utilises more depth and identifies the relative applicability of solutions.*
>
> Occupational health technician: Material loading study

Identifying limitations in the tool is a good way of identifying directions for future development. Lack of necessary guidelines was a key issue that was identified from the case study sessions and the interviews. All of the practitioners mentioned that it would be good to integrate the guidelines with the developed QFD-based matrix. For example, the ergonomist stated during the interview that:

> *It is quite overwhelming when the QFD matrix is initially seen. Necessary instructions need to be provided to help the practitioners on what needs to be done if solutions to a previous requirement are applicable to a subsequent requirement; how to place correlations in the interactions matrix; what to enter in the relationships matrix; what to enter in observations section of the matrix along with assessment data and integrate guidelines in the QFD template to assist in completing the QFD matrix. Um… it might be worthwhile having a link to an example at the top of the QFD matrix to provide a basic understanding on completing the QFD matrix.*
>
> Ergonomist: Stitching operation study

Furthermore, the occupational health technician suggested specific guidelines on what needs to be colour coded need to be integrated to the matrix. In addition, all three practitioners found it difficult to comprehend the triangular interactions matrix. The practitioners that participated in the case study sessions asked how to decide whether there was an interaction or not and place positive or negative interactions on the matrix. The occupational health technician elaborated on this issue.

> *If we understand QFD, as it is, it is a good tool. Without positive and negative interactions, it is just a spreadsheet. It makes you think in a sequence or in a systematic way. Getting the interactions and trying to work out whether it is a positive or a negative we just couldn't get the handle on that. None of us have done QFD. I thought I understood, but when we tried to use it, it didn't work at all. So for that we need practice I think and if we got the handle on positives and negatives I think it is a good tool. The potential of this is high with adequate information on how to do the interactions. Add a bit of background to the interactions matrix. Some slides to show how it is done. The reasoning behind it. Such as a help tool. That would probably work.*
>
> Industrial engineer: Pipe installation study

Regarding the presentation of design information i.e. the risks, user requirements and solutions, the themes identified are summarised in Table 7.9.

Table 7.9. Evaluation of 'presentation of risks and user requirements, and solutions' (within brackets, the number of practitioners expressing views)

Usability	Capabilities	Limitations	Directions for future development
Need to create and paste text boxes with letters N and P for interactions [3]	Good way of presenting information [3]		Prompt to add cost and material information, and time scales in the matrix [2]
Difficult to format the triangular matrix [2]			Automate the process [2]

Usability issues were encountered by the practitioners with respect to the triangular interactions matrix. However, all of the practitioners stressed that this approach was potentially an effective way to presenting design information. For example:

> *The way of presentation and how it is laid out is excellent. We can get a lot of information on one page. They can understand this is what we have done. From the management, it is clearly visible what they thought about it. So yeah, it is excellent. We got the background information collected at various stages. It shows this is where we were, this is what we identified, these are the REBA scores and discomfort etc. and these are the solutions we have taken to implement immediately. I think it is a good tool to show management 'ok this is what we have identified', we highlight them in red, green and amber to show whether it is feasible or not, and what we can do.*
>
> Industrial engineer: Pipe installation study

The occupational health technician specifically mentioned that more depth could be added by including information related to cost and materials. Two of the practitioners (industrial engineer and the occupational health technician) stated the importance of electronically integrating/linking relevant data and figures to the matrix.

Feedback concerning the solutions database is shown in Table 7.10.

Table 7.10. Evaluation of 'recording knowledge in a solutions database for future use' (within brackets, the number of practitioners expressing views)

Usability	Capabilities	Limitations	Directions for future development
Drop-down menus are good [2]	Good and easy way to present design information [2]	Completing the database seemed like added work [2]	Automate the process [2]
Information is clear [2]	A lot of information in one interface [1]	Drop-down menus limit choices [1]	Make provisions to filter data based on projects and different criteria [1]
Tedious to copy information [2]			Colour code or have different tabs for information from different projects [1]
			Add outcomes of stages of projects as feedback [1]
			Prompts to identify standards, guidelines and regulations [1]

The ergonomist stated that the solutions database may be easier to use than the QFD-based matrix, signifying its capacity to store vital information. The occupational health technician also elaborated on this during the interview.

> *Well I think this is probably one of the best parts of the tool because you have got everything in one document. So when you pick the risks or the user requirements, it shows whether you are looking at equipment or a procedure. So it is a step by step guide and I think that is very good and effective. You can address the risk, what it is about, design principles that*

> *you are using, then the actual solution and you can cross reference that with standards and guidelines. Then you know that it is going to be safe.*
>
> Occupational health technician: Material loading study

The practitioners (the ergonomist and occupational health technician) that raised the issue of time to complete the 'solutions database' identified it as 'additional work', signifying that automation of the process is an important path to future development of the tool. In addition, the limitation of the drop-down menus was found to be a limitation. The occupational health technician stated:

> *The form does not allow to enter more than one risk in the field for 'assessed risk'. You can only choose one solution type because sometimes you may have to choose for example equipment and procedure. Can have more than one type.*
>
> Occupational health technician: Material loading study

Information required to assist practitioners in project monitoring to check whether the projects meet the objectives was proposed as an important feature that could be added to the solutions database. For instance:

> *Good to have details regarding what has happened in the company regarding a solution, like feedback to see whether it was achieved, what has been carried out in different stages*
>
> Industrial engineer: Pipe installation study

7.5.9. Performance/usefulness ratings

The ratings for the performance of the elements of the design tool are shown in Figure 7.4. The Likert-type scale used to rate the elements of the design tool was 1= very poor to 7= Excellent. All ratings for performance of the elements of the design tool were excellent or close to excellent, except for the ratings for 'prioritising risks and user requirements' and 'selecting acceptable solutions' by the industrial engineer in the pipe installations study. Usefulness of the design tool as an integrated approach to design was rated as highly useful (mode= 6: range 6-7) in another Likert-type scale (1= not useful to 7= highly useful).

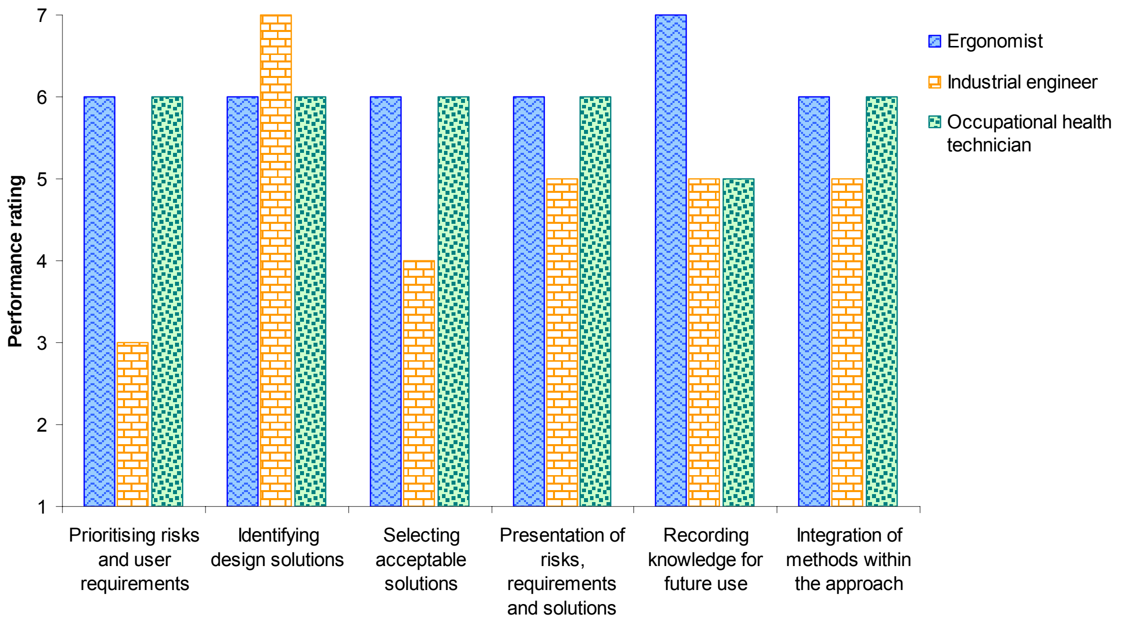


Figure 7.4. Performance ratings for the elements of the design tool

All three practitioners also said that they will continue to use the design tool. For example, the ergonomist in the stitching operation study and the occupational health technician in the material loading study mentioned that they would use the tool in the current project and continue to use it in future projects and modify it if required. The occupational health technician's comment regarding this is quoted:

> *It's good to see whether it works in the industry to see how effective it is and it proved that it can be effective. It can present information and it is very effective. I would definitely think about continuing to use this. I will definitely use this approach, but I will think about possible changes. What I develop and how I develop, I have no idea yet.*
>
> Occupational health technician: Material loading study

Furthermore, the industrial engineer used the QFD-based matrix of the pipe installation study to present the design information to the aircraft design team to redesign the relevant components according to the findings of the study to reduce the workplace risk factors for MSDs. For instance, the industrial engineer commented:

> *It is in a format that you can present. We showed the management, ok, this is what we have identified with facts, highlighted them red, green and amber depending on whether they are feasible or not and what we can do. We recommended the changes to the design team. The changes are*

massive, but we have recommended. They will think about it when they design it.

Industrial engineer: Pipe installation study

7.6. Discussion

The case studies helped provide in-depth feedback on the design tool (and guidance material) from practitioners in the industrial setting. The following discussion is focussed on the usability, capabilities, limitations and directions for future development. At the end of the discussion, an account of the limitations of the study is presented.

The design tool was developed to enhance communication among the stakeholders in the design process. Supporting this, all of the practitioners thought that it was useful and could be used to manage design information and visualise an elaborate picture of the MSD issues and possible solutions before pursuing them, thus helping to share design information in the design process. They also accepted that the tool aims to integrate different methods, and that it will be highly useful as an integrated approach to design. These emphasise the ability of the tool to facilitate the practitioners in the design process in reducing work-related MSDs. This was a key finding of the practitioner interview study and was discussed in Section 6.6. In addition, this aspect of the design tool will be discussed in detail in the following chapter (Chapter 8).

When it comes to using the design tool and its guidance material, the practitioners adopted different approaches to identifying MSD risks and obtaining user requirements (refer Section 7.5.3). The practitioner in the stitching operation study used the REBA, NMQ and whole body discomfort (WBD) scales to assess MSD risks and verified the user identified requirements. In the pipe installation study, REBA and WBD scales only were used and in the material loading study, the NMQ and the WBD scales were used. In order to obtain requirements for design, in the stitching operation study and the material loading study, the practitioners used face-to-face semi-structured interviews while in the pipe installation study, the industrial engineer used a focus group technique. It is interesting to note that the interview guide (Appendix 3.3), which was used in the user requirements study (refer Chapter 3) was successfully used by practitioners even though they were free to use any method of their choice to do so.

In order to define and prioritise the risks and user requirements identified by the workers, all the practitioners used the constant comparative method (Glaser and Straus, 1967; Lincoln and Guba, 1985) together with frequency analysis of the defined themes, where commonly and frequently occurring themes were assigned higher priority. However, the approaches they adopted were different. The industrial engineer in the pipe installation study used a pen and paper based approach, whereas the ergonomist in the stitching operation study and the occupational health technician in the material loading study used the Microsoft® Excel-based tool to facilitate the constant comparative method and frequency ranking. Use of focus group techniques and the difference in the adopted approach to compare themes may be reasons for the low number of identified user requirements in the pipe installation study. In addition, in the pipe installation study, the practitioner was unable to quantify the priorities in terms of the percentage of workers expressing concern. In previous studies however, the analytic hierarchy process (AHP) (Saaty, 1980) has been successfully used to prioritise user requirements when focus groups have been conducted (e.g. Marsot, 2005). Unfortunately, the guidance material only listed a reference to the AHP perhaps deterring the practitioner from using it to obtain a quantified priority order.

In each of the three case studies, six to eight solutions were determined for the two user requirements that the practitioners chose. They were identified using the list of design principles that was made available in the design tool (Appendix 4.2). The practitioners seemed to identify solutions efficiently using the design principles during the case study session. Unfortunately, other methods such as the six hats method (de Bono, 1985) to help brainstorm ideas were not included in the design tool. This prevented the evaluation of the performance of the design principles against other methods that may probably be used to identify innovative/creative solutions. However, practitioner views on the list of design principles were encouraging. For example, the industrial engineer mentioned that ‘the list of design principles was probably the best feature of the tool’. These help justify the inclusion of the list of design principles in the design tool and its capability as an effective tool to help identify design solutions. The ability of TRIZ is discussed in literature under different contexts (e.g. Shirwaiker and Okudan, 2008). Domb and Rantanen (2002) believe that the TRIZ principles can be applied to any problem irrespective of the context. However, no literature was found that specifically discussed the capacity of TRIZ to help reduce workplace risk factors for MSDs. Furthermore, the list of design principles made available in the design tool is an abridged version of TRIZ to suit the conditions in industry, and this also makes it difficult, if not impossible to compare its capability with the literature in this context.

The design tool guides practitioners to list the design solutions obtained without thinking about the feasibility when completing the QFD-based matrix (refer Section

4.6). However, these practitioners were inclined to omit the solutions that were potentially unfeasible. No solutions were coded in RED in the QFD-based matrix to manage and present design information in two of the case studies. There could be instances where a potentially infeasible solution in one scenario becomes feasible in another; therefore, potentially usable solutions could get missed out. Thus, more guidance needs to be provided in this regard. No literature was found that explored how the practitioners identify feasible solutions and make design decisions to compare the results of the current study. However, there is evidence to show that the QFD house of quality approach uses multipliers (rating scales) to quantify the importance of solutions (Akao, 1990; Terninko, 1997) at the initial stages of the design process.

The design tool guides the practitioners to identify design solutions under four different solution types, i.e. equipment, facilities, procedures and training (refer Section 4.5). However, the practitioners in the current study seemed to concentrate more on providing design solutions to improve equipment. For example, the practitioner in the stitching operation study only provided solutions to equipment although this practitioner could have identified solutions to improve the facility, procedures and training in order to reduce the workplace risks. This may be due to the fact that the objective of this practitioner was to improve the stitcher. In the material loading study, the occupational health technician limited the design solutions to only equipment and procedures, and concentrated more on equipment. However, in the pipe installation study, the practitioner identified design solutions with respect to all of the solution types. This practitioner also specified two of the solution types as ‘other’ although they could have been categorised as facility and procedure. This suggests that more guidance is required to help the practitioners in selecting appropriate design solutions with respect to all possible solution types.

In the stitching operation and material loading studies, the practitioners completed the solutions database after the QFD-based matrix, and copied the design information from the QFD-based matrix to the relevant fields of the solutions database. It is interesting that in the pipe installation study, the industrial engineer completed the solutions database before the QFD-based matrix and copied design information from the solutions database to the QFD-based matrix. This procedure was used by this practitioner in order to reduce the effort required to identify and record design solutions since the solutions database included the design principles in a drop-down menu. This adaptation of the process was to limit the need to keep open several windows at a given time, which was identified as a limitation. This also emphasises the flexibility of the features of the design tool.

However, there were also usability issues and limitations in the guidance material that lead to recognising the directions for future development. These were inadequacy of guidance to help practitioners; difficulty to browse through the themes; inappropriate formatting; having to type in the same information in different locations and having to keep several windows open at a given time. Similar shortcomings have been identified in the existing QFD software tools available to practitioners (Herzwurm et al., 1997). A tool with automated processes and simpler guidelines is important for future development of the tool. These suggestions correspond with the features for an ‘ideal’ QFD software tool suggested by Herzwurm et al. (1997). They suggest 71 features based on statements of positive and negative experiences of practitioners using QFD software tools. These may be amalgamated with the identified directions for future development in the current study to make the design tool more user-friendly. It can also make the tool more effective and efficient in terms of its ability to manage and share design information/knowledge in the design process and enhance communication among stakeholders of the design process. A detailed discussion of the future work needed pertinent to the design tool and the overall research project recognised from the findings of both this and the practitioner interview study (refer Chapter 6) is presented in Chapter 8.

7.6.1. Limitations of the study

The practitioners may tend to change their behaviour in order to suit the evaluation study when the observer is present when collecting data. In such case, there is a possibility of providing only positive or only negative suggestions by the practitioners to please/satisfy the researcher or comply with the researcher’s wishes giving rise to a biased evaluation of the design tool. This phenomenon known as the ‘Hawthorn effect’ is one of the noteworthy limitations of studies of this nature, and is discussed extensively in the literature (McKinnon, 1988; Wickström and Bendix, 2000; McCarney et al., 2007). On the contrary, there is a possibility of practitioners being discouraged or antagonised by the researcher and the methods being used. These affect the reliability and validity of field studies (McKinnon, 1988). However, a friendly environment was established with the practitioners during the studies, and they were also clearly informed regarding the objectives of the study to ensure the acquisition of their unbiased views.

The case studies were conducted in facilities that belong to large manufacturing companies employing a large number of people (refer Section 7.5.2). Therefore, bounded systems selected for the studies could be assumed to represent a sample of the worker population employed in the manufacturing industrial sector. The work tasks were diverse involving a hand tool (stitchers) operation, a pipe installation process in a restricted environment and a manual material handling task. It is plausible to assume that the case studies were conducted in different work environments even though the tool was implemented by practitioners in only manufacturing facilities.

All of the case studies involved a ‘stationary workstation and a cyclic work task’, which constitutes only one of the four different combinations of work characteristics discussed in literature (Denis et al., 2008). Therefore, variety with regard to work characteristics was not achieved in the practitioner case studies. The effect of this shortcoming is likely to be minimal as evaluating this feature of the design tool to ‘identify risks and obtain user requirements’ was not central to this study.

Identifying potential risks, obtaining user requirements and prioritising them were carried out by the practitioners prior to the case study sessions. The interview guide included as part of the guidance material was used in case study 1 (stitching operation) and case study 3 (material loading). Only, parts of it were used in case study 2 (pipe installation) (refer Section 7.5.3). In addition, guidance for ‘prioritising the risks and user requirements’ was only used by the practitioners in the first and third case studies (refer Section 7.5.4). These provided a means of speculating the effectiveness and usability of the relevant tools as discussed earlier in this discussion.

Another limitation of the study was the inability to quantify aspects such as the usability, functionality and effectiveness of the individual tools that were made available within guidance material. Usability studies need to be conducted in order to quantify these aspects of tools (Rosenbaum, 1989; Armstrong et al., 2002; Pace, 2003). For example, Armstrong et al. (2002), explains that usability evaluation approaches do not offer the rigour of empirical usability testing. However, often they require extensive resources, time and expertise to gain the clearest possible understanding of where a design succeeds or fails for its users. Thus, usability testing can be recommended as future work for further refining such tools.

7.7. Summary

The design tool (and guidance material) was evaluated using a case study approach in order to understand some of its strengths and weaknesses. Three case studies were conducted involving the respective practitioners (i.e. an ergonomist, industrial engineer and occupational health technician). The case studies were conducted on site by the practitioners and the work tasks selected were streamlined with their company directives to review the work tasks and improve them.

The three case studies involved a stitching operation used in a tyre repair manufacturing facility, a pipe installation process in an aircraft wing-box and a material loading work task in a poly vinyl chloride (PVC) panel manufacturing plant. Initially, the case study sessions were held where the practitioners used the design tool (and guidance material). Observational data were recorded, and face-to-face semi-structured interviews were held with the participating practitioners. Documentary evidence was also gathered whenever possible.

The findings showed that the design tool would be very useful in managing and presenting design information. In particular, practitioners liked being provided with design principles to help systematically identify design solutions to reduce risks and using the quality function deployment (QFD) matrices to present such information. Limitations of the tool were identified as inadequacy of instructions, the lack of automated procedures and the time required to set up and learn. Despite these, the design tool (and guidance material) seems to have potential in facilitating the sharing of design information among the stakeholders of the design process.

8. Discussion

8.1. Introduction

Research indicates that work-related musculoskeletal disorders (MSDs) are commonplace in industrialised countries and rising in the developing nations (e.g. Gauthy, 2005; Choi, 2005; HSE, 2008). Despite intervention programmes conducted in workplaces (Kogi, 2008; Zink et al., 2008), work-related MSDs continue to be a problem causing alarming expenses to industry. Effective industrial system design to match worker needs is suggested as a way of preventing workplace risk factors for developing MSDs (Buckle, 2005; Karwowski, 2005). However, a communication barrier exists between the workers (users) and the different practitioners involved in design hindering the effective flow of design information in the design process (Shinnar et al., 2004; Broberg, 2007a; Broberg, 2007b). The practitioners involved in the design process include engineers, designers and others such as ergonomists, occupational health professionals and health and safety personnel that influence design decisions.

This thesis is concerned with the reduction of work-related MSDs in industry by helping to improve design through enhancing communication among the stakeholders in the design process, in particular, the potential of a quality function deployment (QFD)-based design tool. To this end, research (user requirements study) was conducted in three case study areas to 'evaluate user knowledge and ability to identify workplace risks and the subsequent requirements for design in order to reduce the risk factors for developing MSDs' (refer Chapter 3). Following this, a QFD-based design tool (and guidance material) was developed (refer Chapter 4). Finally, the tool was subjected to a three faceted evaluation process that included a questionnaire survey (refer Chapter 5), face-to-face interviews with practitioners (refer Chapter 6) and case studies in the industrial setting (refer Chapter 7).

Findings significant to the studies were discussed at the end of the respective chapters (refer Sections 3.6, 5.6, 6.6 and 7.6). Therefore, this chapter will focus primarily on the discussion of the overall research and how the findings of the individual chapters link together and compare with the literature. This discussion is structured according to strengths and weaknesses of the different aspects of the design tool. Subsequent to this, the implications of the research in terms of its contribution to the body of knowledge and relevance to the industry are discussed. This is followed by drawing recommendations for future work pertinent to the tool. Finally, the conclusions of the research project are listed.

8.2. Enhancing communication in the design process

The findings of the research suggest that the tool encourages an approach to enhance communication among the stakeholders with different levels of knowledge of work-related MSDs and design. For instance, most of the practitioners from the survey highly rated the importance of an integrated design approach. One practitioner specifically reported that the ability to share information effectively with cross-functional teams was an important requirement of any design tool. In addition, half of the practitioners that participated in the interviews stated that the tool will help collaboration/communication with others that are involved in the design process (refer Section 6.5.2). As discussed in Chapter 2, the literature supports the idea that communication of design information between the users that actively interact with the work systems and the practitioners involved in design is quintessential to help reduce work-related MSDs (Graves, 1992; Wilson, 1994; Boy, 2006). For example, the study by Graves (1992) describes how co-operation between workers and medical, engineering and ergonomics disciplines resulted in the improvement of an assembly line redesign that ultimately helped reduce the risk of upper limb disorders. QFD provides a tool for communication and it is a powerful tool to build a system for design (Yoshizawa, 1997 cited by Akao and Mazur, 2003), and has been widely used in industry (Chan and Wu, 2002). The unparalleled flexibility that QFD offers when compared with other similar techniques such as axiomatic design makes it possible to be adapted to cater for different needs in the industry. Participatory models that engage key stakeholders is considered as important in formulating work-related MSD prevention measures (Mital, 1995; Buckle, 2005), and design is strongly advocated as a prevention strategy (Amell and Kumar, 2001).

Strengthening this idea further, all of the practitioners that took part in the case studies reported that the tool was useful in managing design information and for visualising an elaborate picture of the MSD issues and potential solutions before pursuing them (refer Section 7.5.8). This is an important phase of conceptual design. For instance, Panchal et al. (2007) describe that concurrent engineering processes strive to achieve coordination among stakeholders of the design process, and discuss that the use of set-based design approaches to communicate sets of solutions to the design teams is advantageous compared with optimised single solutions. Aldrich and Stauffer (1995) elaborate on the huge amounts of data that need to be accessed and manipulated during design tasks and emphasise the importance of representing design information in categories for designers to use. This is important in relation to the current research project where categories of information vital for design such as user requirements, solutions, standards, guidelines and regulations and interactions between solutions were encapsulated in the QFD house of quality-based tool. This allows visualisation in a single interface enabling stakeholders in the design process to share knowledge.

Interestingly, the ability to visualise detailed design information and being able to record the rationale behind user requirements, i.e. transparency as to what the user requirements were based on, was highlighted as important by two survey respondents. Sharing such knowledge among the stakeholders in the design process will invariably result in more effective design (Wilson, 1994; Boy, 2006). This was also specifically identified by two of the respondents in the practitioner survey: the ability to share information effectively with cross-functional teams. Involving workers in identifying workplace risks and the subsequent design requirements is also likely to empower and motivate them to take a more active role in the reduction of workplace risk factors for developing MSDs (Wilson, 1994; Zink et al., 2008). Moreover, the resulting changes are more likely to be accepted by the workers if they are involved in the design process (Wilson and Morris, 2004). However, Neumann et al. (2009) discuss that different stakeholders consider ergonomics and productivity as separate entities, and this discourages them from effectively involving in the exercises to reduce work-related MSDs. Therefore, the generation of interest in these stakeholders would be necessary in order to harness benefits of using the QFD-based tool.

The practitioner survey revealed that the majority of the practitioners value a tool that could integrate the different phases of the design process. In the case studies, all of the practitioners put a high rating on the performance of the design tool as an approach to integrate the design process. Integration of the activities in the design process would invariably help effective communication, and this aspect of the design tool can be used to arouse interest of the stakeholders. Research from a variety of fields can be quoted to appreciate the value of QFD as a viable approach to integrate the different phases in the design process as discussed in Section 4.2. By integrating the design process, QFD effectively tries to enhance communication of information throughout the design process to ensure quality of design (Akao, 1990; Day, 1993; Terninko, 1997; Akao and Mazur, 2003). A detailed discussion regarding this aspect of the tool was also included in Section 6.6.

It is worthwhile comparing aspects of the design tool with the participatory ergonomics framework (PEF), an established participatory ergonomics approach, proposed by Haines et al. (2002) to understand the impact of the tool on the design process and its stakeholders. The PEF consists of several dimensions: permanence, involvement, level of influence, decision making, mix of participants, requirements to participate, focus, remit and the role of ergonomics specialist as discussed in Section 2.4.2. This can be used to discuss where the design tool sits on the participatory ergonomics continuum and it is elaborated below according to the dimensions of PEF.

- Permanence: The findings from the research indicate that the design tool could facilitate **temporary** type projects, which can take place outside the organisational structure. For instance, all three case studies were conducted as temporary projects. It could also facilitate **ongoing** type projects, which are integrated with the structure of the organisation. For example, three of the participants in the practitioner interview study said that the tool could be adapted to suit their companies.
- Involvement: The tool promotes **full direct participation** of the workers and the practitioners in the design process. It emphasises obtaining user requirements by conducting individual face-to-face interviews with the workers that are directly involved with the work task being studied and requirements can be prioritised based on their narratives. Furthermore, in the pipe installation case study, workers were directly involved in identifying design solutions as well.
- Level of influence: Although the application of the design tool influences the entire organisation or a department, the most influence is on the **work group/team** since the tool tries to reduce work-related MSDs among workers by focusing on individual work tasks and the users involved with them.
- Decision making: The design tool promotes workers to come up with the requirements to reduce the workplace risks for MSDs. The traditional emphasis of QFD is user driven design, and thus, the design tool depends on the requirements expressed by the users/workers. The practitioner that uses the design tool can also involve workers in every stage of the design process to obtain their input to make maximum use of the approach. Therefore, the QFD-based design tool involves mainly **group delegation** type of decision making.
- Mix of participants: The design tool tries to enhance communication among the stakeholders of the design process that includes users/workers (**operators**), practitioners (**internal specialist/technical staff**) and design teams (e.g. **cross industry organisation**). The design process also involves other partners such as managers and suppliers. Therefore, it could be considered that the design tool facilitates the involvement of all the participants that are listed in the PEF.

- Requirement to participate: In order to obtain design information to communicate and develop usable solutions, the practitioner needs to involve different stakeholders. However, participation of stakeholders in this exercise is **voluntary** to facilitate the acquisition of genuine information.
- Focus: The design tool intends to facilitate the development of equipment, facilities, procedures and training in order to reduce workplace risk factors for developing MSDs. This was evident by the solutions obtained during the case studies to evaluate the tool. Thus, the focus of the tool is on **physical design/specification of equipment/workplaces/work tasks and work organisation**.
- Remit: The design tool consists of six features to cover the design process. These features facilitate mainly the **problem identification** (identify risks and user requirements) and **solution development** (identifying solutions and selecting acceptable solutions) phases. It could also be used to **monitor/oversee the process** as well, since the QFD-based matrix would present an elaborate picture of the design information. This was identified by four of the practitioners in the interview study and all the practitioners in the case studies. However, the tool does not cover implementation of change.
- Role of the ergonomics specialist: In the implementation process of the design tool, the practitioner has to **initiate and guide the process**. In addition, the practitioner needs to validate the user requirements by conducting observations. Therefore, the practitioner **acts as an expert** and need to be **available for consultation**.

The approach followed by the design tool makes it possible to effectively communicate design information with cross-functional teams, which is vital for good interdisciplinary relationships as reported by Mayfield and Hill (2007). One of the respondents in the practitioner survey specifically reported that the tool needs to ensure that a systems approach is considered recognising that almost all factors will interact. The popularity and usefulness of the systems ergonomics approach, where organisations, teams and types of technology are considered as interrelated components (i.e. a system) when changing any aspect of the system, are widely discussed in the literature emphasising its importance to help integrate cross-functional teams (Neumann et al., 2009; Waterson, 2009). For instance, Neumann et al. (2009) reports from a study in a manufacturing industry that the use of the systems approach to integrate the workers to the overall development process of the organisation helped to identify and implement a number of improvements. Importantly, QFD, a well known systems engineering approach used to integrate ergonomics and present design information, which was extensively discussed in Chapter 4, is identified in the literature as a viable aid to effective communication of design information in the design process. For example, by researching on hand tool design, Marsot (2005) concludes that QFD is a methodological approach to integrate ergonomics in the design stage. These studies justify the use of QFD as a basis to develop the design tool to help communication among stakeholders and reduce workplace risk factors for developing MSDs. However, the traditional QFD house of quality matrix has been used in these studies, and no literature was found that reported the use of an approach, which deviated from the classical QFD methodology.

While the practitioners appreciated the attempt to integrate the design process and develop a tool to manage and present design information, they also pointed out limitations in the tool that would potentially act as a barrier to effective communication. The most significant flaw that all of the practitioners in the interview study mentioned was the lack of guidance to easily understand the design tool and its procedures. This issue was discussed at length in Section 6.6. Lack of guidance was again pointed out in the practitioner case studies by all three participants. This hampers the effective use of the useful methods made available in the design tool to streamline the phases in the design process. As discussed in Chapter 6, step-by-step guidance was not developed, and only brief guidelines were included within the guidance material due to time constraints. Limited time and resources are discussed as major concerns for the product developers to limit the time spent in documenting user guidance for the products that they develop (Kendall and Kendall, 1999). It results in inadequate user guidance and affects the usability of the products being developed and this shortcoming needs to be addressed in order to help the practitioners to use the tool effectively.

Another salient limitation identified in both practitioner interview study and the case studies was the time that it takes to complete the process, which discourages its use. One reason for this is the repetition of tasks, for example, when entering data into the solutions database, data entry tasks are duplicated. As discussed by Bruce et al. (1995), the time required to complete the projects could increase with the increase of the scale and complexity of the projects. This issue was also discussed in Section 6.6. Another reason is the time it takes to complete the individual tools and techniques made available within the guidance material of the tool, for example, the practitioner in the pipe installation study mentioned that the interview guide suggested is too long for industry. These are also issues that need to be taken into consideration for the future development of the tool.

The other prominent issue that was raised by two of the practitioners in the interview study was that the tool may not be applicable to every project. Franceschini and Rossetto (1998) elucidate, management of QFD matrices become increasingly difficult with the increase of complexity of the application substantiating this view. Opposing this perspective, practitioners in the case studies did not identify this as a limitation. Besides, QFD has been used successfully in various sectors and for different applications (Chan and Wu, 2002). However, the tool needs to be tested in different scenarios under different contexts to ascertain whether it could work equally well in every situation.

The view regarding the inability of the tool to be used in every project may have been expressed due to the inadequate guidance with regard to understanding the tool. In addition, the practitioners observed that the QFD-based matrix is unable to be separated into manageable sections when the problem gets complex and size of the matrix becomes large. Contradicting this view, Herzwurm et al. (1997) discuss that a high product complexity does not deter the use of QFD. They also suggest that structured project organisation, project specific adjustment using supplementary methods and detailed analysis of the relationships between requirements and solutions are vital for the success of the QFD approach. Interestingly, one of the practitioners in the interview study also stated that the tool will work well for complex problems expressing the ability of QFD to effectively integrate the design process. However, this issue needs to be studied further.

8.2.1. Involvement of workers in the design process

Research was conducted to evaluate user knowledge and ability to identify workplace risks and the subsequent requirements for design in order to reduce the risk factors for developing work-related MSDs. The findings of the ‘user requirements study’ (refer Chapter 3) provided convincing evidence to show that the workers in general were able to participate in the design process to identify risks and suggest requirements for design in order to reduce the work-related MSDs that they experience. In particular, the workers were able to identify risks and requirements for task elements with rapid entire body assessment (REBA) risk levels greater than or equal to medium as discussed in

Chapter 3. They were also inclined to express concerns related to more frequently occurring load and posture-based workplace risks than less frequent tasks. Teschke et al. (2009) used a data-logging inclinometer, expert observations and self-report methods in a study of 50 heavy industry worksites. Their observations and self-reports provided estimates of time spent in various postures in materials handling and vehicle use. However, self-reported data from the workers themselves tended to under-report less common tasks. This is similar to the findings of the current study. Nevertheless, compelling evidence is present in the literature to show that the users (workers) with experience in particular work tasks are able to identify requirements for design (e.g. Engelbrektsson, 2002; Woods and Buckle, 2005). This was discussed in detail in Section 3.6.

In the practitioner case studies (refer Chapter 7), although not specifically assessed, the workers also participated effectively in the design process and contributed their knowledge and experience to identify requirements for design to reduce work-related MSDs. It is recommended in the literature to engage users early in the design process to facilitate communication between the users and the design practitioners. For instance, Gyi et al. (2010) suggest from a study to evaluate older users' ability to understand virtual models of gardening equipment that, the use of such models could be used to facilitate communication between the users and the designers. This research also emphasises the use of a design tool to facilitate communication.

As mentioned earlier, the main risks and design requirements identified by the workers were related to the task elements with high REBA risk levels. An association between the REBA risk levels and the number of workers identifying MSD risks and requirements for design was apparent as discussed for the cleaners', joiners', and plumbers' in Section 3.6. A similar association was observed in the 'stitching operations study' (refer Section 7.5.3) where the task element 'repairing beads and punctures' showed the highest REBA risk levels (high/very high) and the highest number of suggestions for design expressed by the workers. For example, the 'need to be able to grip the handle firmly as a lot of weight needs to be put on to the handle' was viewed by 84% of the workers as a requirement for design. This finding from the 'practitioner case studies' add strength to the findings of the 'user requirements study' and indicates that efforts should be made to include workers in the design process to help reduce workplace risk factors for developing MSDs. To the researcher's knowledge, no evidence was available in the literature that opposed these findings.

In addition, patterns could be seen among participant groups in the 'user requirements study' with respect to prevalence and discomfort data (refer Section 3.6). A similar picture was observed among the worker groups that took part in the case studies. For instance, the workers in the stitching operation study (refer Section 7.5.3) showed a higher period and point prevalence of musculoskeletal troubles in the shoulders, hands and fingers. Corresponding discomfort ratings were also high. Interestingly, these workers identified more risks and requirements for design related to the task elements that involved body areas, which presented higher exposure to MSD risks. The studies by Ueno et al. (1999) and Holmström and Engholm (2003) with construction workers report that the variation in MSD prevalence across different trades is due to the variation in the level of physical exposure of the workers. This is a result of workers in different trades being exposed to different work-related risk factors for MSDs due to the variety of task elements they need to perform and indicates that physical exposure is directly related to the work tasks. Therefore, it could be argued that the requirements for design that the workers specify are related to the task elements they carry out, and that workers tend to emphasise on task elements that give rise to MSD problems. This may also generate conflicting requirements for design across different work situations. Thus, it is important to customise or adapt designs to suit varying design requirements to reduce workplace risks for developing MSDs that stem from different users and work situations. For this, Brouwer and van der Voort (2008) suggest the use of scenario-based approaches to design where different use situations are taken into account when designing usable products to cater for varied requirements for design. This emphasises the usefulness of the QFD-based design tool proposed in this thesis.

It is imperative to deploy worker (user) knowledge in the design process. The involvement of workers themselves in the design process is paramount to ensure effective communication of design information to the practitioners involved in design, and has shown promise in helping to improve design to reduce work-related MSDs. This aspect is well documented in the literature (e.g. Kuorinka and Patry, 1995; Rivilis et al., 2006; Vink and van Eijk, 2007; Kramer et al., 2010). Furthermore, worker involvement in intervention processes is reported to provide lasting solutions by instigating a sense of ownership of the solutions that are implemented. This is a key attribute of the participatory intervention programmes discussed in the literature (refer Sections 2.4 and 2.5). With respect to product development, Chamorro-Koc et al. (2009) concludes from a study with 20 product users and five product designers that inclusion and consideration of experiential and contextual aspects can assist the design of user-product interactions. In addition, Kramer et al. (2010) involved workers, consultants and company representatives in a study to assess 20 innovative tools that potentially reduced the risk of MSDs. They discuss the fact that workers were able to distinguish the improvements made to the tools compared with the original ones in terms of ergonomics. These further support the view that workers are able to participate in the design process to facilitate communication of design information. However, in their study, Kramer et al. (2010) also discuss that the company representatives, contrary to the workers, focused on the importance of the innovative tools in terms of improving productivity, emphasising the diversity and disparity in the thinking processes of the different stakeholders in the design process signifying the importance of involving workers in the design process.

While appreciating the benefits of user involvement in the design process, two of the practitioners in the interview study mentioned that co-operation of workers is needed and it is usually difficult to obtain. Signifying this fact, Herzwurm et al. (1997) report that involvement of employees with a positive attitude is necessary to ensure effective communication in the design process. Broberg and Hermund (2007) conclude from their study of four cases that involvement of workers in the design process can be obtained by practitioners acting as facilitators. The facilitator can train workers in ergonomics and the workers can be shown that the designers expect and value their input. For instance, Gould and Lewis (1985) encourage design teams to interact with workers to obtain user knowledge and training designers in using the systems that are used to enlighten them about particular work tasks. Furthermore, Khalid (2006) describes a framework that incorporates users, tasks, products and environments, which helps to harness user perspectives of designs. Such knowledge could be used to obtain the co-operation of the workers in the design process.

Another caution was expressed by one of the practitioners who was concerned that workers may miss identifying the risks in their work and subsequent requirements for design. The use of multiple methods and triangulating the data to draw conclusions can help minimise the adverse effects of using single methods (Moran-Ellis et al., 2006). They state that researchers should try to obtain additional information by bringing two or more methods together. Elaborating more on this issue, Meetoo and Temple (2003) argue that triangulation does not necessarily prove the validity of studies simply because different methods reveal similar findings, but information from different methods can be effectively used to identify new findings. Supporting this view, Baecker et al. (2000) suggest the triangulation of methods provides several perspectives as each can illuminate a different aspect of the problem.

8.2.2. Involvement of practitioners in the design process

Practitioner evaluations of the design tool in the interview study (refer Section 6.5) and the case studies (refer Section 7.5) indicate its potential impact on the entire design process. Practitioners in general believed that the QFD-based design tool would help them to integrate the design process and manage and share design information. For example, all of the practitioners that took part in the case studies highly valued the design principles provided to help them generate creative ideas and the ability of the tool to help select acceptable solutions.

Involvement of practitioners in the design process is important (Cullen, 2007; Vink et al., 2008). However, according to a questionnaire survey with 300 practitioners that were involved in participatory processes (Vink et al., 2008), practitioners such as ergonomists do not get equally involved throughout the participatory process. This is not ideal in terms of identifying and providing effective solutions to prevent work-related musculoskeletal problems in industry. This study also showed that the ergonomics practitioners' role diminished towards the end of the participatory process and that designers showed higher participation in the generation of ideas. The lack of involvement of ergonomists throughout the design process forms a barrier to effective design. Similar findings were revealed in a study by Williams and Haslam (2006) with 183 respondents from different countries to assess the key competencies ergonomics professionals should have. They reveal that the respondents were less competent in planning, delivery and evaluation of interventions to deal with ergonomics problems than the identification and recording of the problems.

As discussed in Section 8.2.1, Broberg and Hermund (2007) report that practitioners such as occupational health practitioners and ergonomists can facilitate the communication process between the users and the design teams. Providing techniques in the design tool such as 'design principles for creative problem solving' will help expand practitioner knowledge and encourage more involvement in the design process, especially in the idea generation and selection phases. This would enable practitioners to extend their capacity and hence acquire more required competencies as stipulated in the International Ergonomics Association (IEA) web site. However, the literature also presents barriers to implementing design methods (Green and Bonollo, 2002) indicating the potential difficulty in integrating the proposed design tool within the practitioner community.

In order to provide an account of the methods that were suggested within the guidance material, a critique including their usefulness and limitations is presented in the following section.

8.3. The design tool

The design tool presented in Chapter 4 and subsequently evaluated in Chapters 5, 6 and 7 essentially proposes a way of thinking; a philosophy for practitioners to ensure that the requirements of the users are reflected in what is ultimately designed and produced. The design tool presented in this thesis is an attempt to bridge the gap between the users and design practitioners since a mismatch between the user requirements and what is ultimately produced is evident in the literature (Slappendel, 1994; Shinnar et al., 2004; Broberg, 2007a; Broberg, 2007b),

Suitable methods needed to be adopted in order to effectively and efficiently harness worker knowledge and ensure communication to the relevant practitioners of design. Supporting this notion, the urgent need for methods/tools to elicit requirements from users and inform the design process is advocated in a case study reported by Gyi et al. (2006) where users were involved in a workshop to provide the user perspective when developing flexible packaging. As reported by Wilson (1994), specifications for systems should be supplemented by reasoned justifications when providing design information for the practitioners of design such as designers and engineers. This essentially means that the adopted tools and techniques should seamlessly integrate with the procedures of the practitioners of design to collectively improve workplace health. However, as discussed in Section 8.2, the general lack of guidance in using the tool was identified as a limitation by all of the practitioners in both the practitioner interviews and case studies. The specific elements that make up the design tool are now discussed in terms of their strengths and weaknesses.

8.3.1. Methods to identify risks and obtain user requirements

The user requirements study employed interview and observation techniques in combination to identify risks for MSDs and obtain user requirements. The proformas for these together with other popular methods such as the whole body discomfort (WBD) scales were made available in the design tool to facilitate the practitioners in this process.

The practitioners in the practitioner survey reported that they generally employed user-interviews (96%) and observation techniques (91%) to understand user requirements.

In addition, five of the practitioners in the interview study stated that providing examples of these would be helpful for practitioners with limited experience. This signifies the importance of including methods that could be readily used by the practitioners to identify risks for MSDs and user requirements. In the practitioner survey, two of the practitioners reported that the rationale behind each of the user requirements needs to be recorded. For this, detailed information pertinent to each requirement needs to be elicited from the workplace, and to facilitate this, useful methods such as interview guides, observations and REBA proforma were suggested and made available within the guidance material of the tool. In the practitioner interview study, all of the practitioners appreciated these useful methods.

In the practitioner case studies, two of the three practitioners used interview and observation techniques whilst the other used focus group and observation techniques to obtain user requirements. This indicates the familiarity and popularity of these techniques among the practitioners. Two of the practitioners used the entire interview guide suggested by the researcher. REBA was used by two of the practitioners and WBD scales were used by all three participants even though they were asked to use any methods of their choice to collect data. This shows clearly that the methods suggested were appreciated by the practitioners and were convenient to use. Unfortunately, further information could not be elicited regarding this, and hence it is unclear why the practitioners deviated from their familiar approach to identifying user requirements and confined themselves largely to the material included in the design tool during their studies.

Similar methods/approaches to suggestions made in the tool are widely published, and are established as standard techniques for user evaluation (Konz, 1990; Wilson and Corlett, 1990; Chengalur et al., 2004; Stanton et al., 2005). These indicate the extensive application of such techniques in industry, and help justify their inclusion within the guidance material. In addition, specific techniques such as REBA and WBD scales are widely used by the practitioners in the industry (e.g. Corlett, 1990; Bao et al., 2007). Findings of this thesis also suggest the potential and importance of suggesting methods for inclusion in the guidance material to facilitate identifying MSD risks. In addition, these findings highlight the fact that practitioners do not rely on a single technique to assess MSD risk and obtain design requirements, but a combination. Supporting this, Spielholz et al. (2001) report from their research that self-reported data were the least precise assessment method and overestimated the exposure level. Observation and direct measurement methods provided precise assessments for different body areas. Similar findings are reported in the study by Teschke et al. (2009) in 50 heavy industry worksites. These show the importance of using methods in combination.

While appreciating that the methods made available in the tool could be readily used, six of the practitioners that participated in the interview study and all of the practitioners that took part in the case studies also mentioned limitations. Lack of guidance for the practitioners on aspects such as selection of appropriate methods, using the suggested methods and comprehending other information such as determining adequate sample sizes were listed as major limitations. As discussed earlier, guidance development needs time and other resources and published material by various authors (e.g. Wilson and Corlett, 1990; Chengalur et al., 2004; Stanton et al., 2005) could be used along with techniques for documentation used in software engineering (Kendall and Kendall, 1999) to help develop user guidance. These limitations are further discussed under future work (refer Section 8.7).

8.3.2. Tool to prioritise the risks and user requirements

The design tool included a Microsoft® Excel-based tool to help prioritise the user requirements identified. The importance of this tool is emphasised due to the lack of methods currently being used by practitioners in this regard. A striking finding of the practitioner survey (refer Chapter 5) is that only 39% of the practitioners reported using formal methods for prioritisation. These practitioners used risk assessment data to prioritise information gathered from techniques such as user interviews and observations. However, according to a review by David (2005), risk assessment techniques are based on hypothetical values making them unsuitable for accurate prioritisation of risks. This essentially means that these cannot be conveniently integrated to the design process to help prioritise risks and user requirements. This was highlighted in one of the comments by a respondent in the practitioner survey, who said that the tool should be able to manage single devoted tools such as the lifting index for manual material handling instead of tools that consider all risks for MSDs as a whole such as REBA. This was mentioned despite the popularity of risk assessment techniques such as REBA (Dempsey et al., 2005). Hence, risk assessments may only be used to verify the requirements for design identified using other techniques such as interviews, focus groups and observations.

Furthermore, in the practitioner survey, QFD and proprietary techniques were also reported as methods to prioritise user requirements, but details were not elicited.

According to literature, QFD does not have a prioritisation technique of its own (Akao, 1990), but utilises techniques developed elsewhere such as analytic hierarchy process (AHP) (Saaty, 1980) and rating scales. Although the use of AHP gives an objective priority value (on a ratio scale) to each of the items being prioritised, the process takes time. Rating scales can be used to rank order items on a list, but using subjective ratings provided by participants to assign objective values to the items on the list can be flawed (Clason and Dormody, 1994; Annett, 2002; Göb et al., 2007). In addition, the risks and user requirements need to be first identified before using these techniques. Therefore, more convenient methods are needed for this purpose.

The findings of the current research has accentuated the importance of the inclusion of the Microsoft® Excel-based prioritisation tool that was developed by adapting the constant comparative method described in grounded theory (Glaser and Strauss, 1967; Lincoln and Guba, 1985; Erlandson et al., 1993) and counting frequencies of the identified themes. This was developed and successfully used to analyse the requirements for design in the user requirements study and was subsequently included in the design tool. It was used in both stitching operation and material loading case studies with success to help prioritise the user identified risks and requirements. It was highly appreciated by the practitioners interviewed, and those who took part in the case studies justified its inclusion in the design tool and its usefulness. In the practitioner interview study, all of the practitioners mentioned that the prioritisation tool for user requirements was important and useful. In the case studies, the two practitioners that used the tool stated that it provided a structured, simple and effective way to prioritise themes. This may be due to the tool's ability to quickly update the priorities in the themes as they are extracted from the interviews and copied to the Excel sheet. The use of Microsoft® Excel as a tool for qualitative analysis is discussed in the literature. For example, Meyer and Avery (2009) elucidate that the structure, data manipulation and display features of Excel can be utilised to facilitate qualitative data analysis. However, no literature was found that presented an Excel-based tool in the way used by this research.

The practitioner interview study was also instrumental in identifying several significant limitations of this prioritisation tool such as lack of guidance and missing out on important requirements. Again guidance to understand the process and the time required to complete the process were the most significant limitations identified by the practitioners.

8.3.3. TRIZ-based design principles

A list of design principles based on 'the forty principles of design' in TRIZ (Terninko, et al., 1998; Rantanen and Domb, 2002) was important to facilitate practitioners to identify solutions in a structured manner. As reviewed in Chapter 4, there are various techniques available to aid brainstorming to help identify creative solutions to the problems identified in the industry. Research suggests the use of brainstorming (e.g. Parkin et al., 2000) and experience-based expert judgements (e.g. Marsot, 2005; Kuijt-Evers et al., 2009) to develop solutions. However, no specific methods had been reported in the literature that facilitates this process.

The practitioners that responded to the questionnaire survey (refer Chapter 5) also confirmed the findings from the literature. Out of the 23 respondents that completed the entire questionnaire, ergonomics guidelines (96%), experience-based judgements (78%), studying similar cases (65%) and innovation (43%) were used to develop design solutions, but none of the practitioners reported the use of systematic approaches to identify innovative solutions. Unfortunately, the practitioners that mentioned the use of proprietary tools for innovation did not give any details. In addition, the performance ratings of the practitioners for the 'methods to help identify design solutions to address requirements' were mixed (refer Figure 5.3.d). This implies that they do not agree that there are appropriate methods to help identify solutions. At the same time, the importance of such methods to help identify solutions was rated as very high (refer Figure 5.4.d) indicating the need for such techniques.

Therefore, the TRIZ-based list of design principles can be considered as an important contribution to the practitioner community involved in reducing work-related MSDs. This was justified by all of the practitioners that participated in the evaluation studies (refer Chapter 6 and 7). For instance, all of the practitioners that were interviewed were enthusiastic that the design principles were very good and would work in the industry. The practitioners that used the design tool all highly rated the design principles and said that they were very useful and helpful to identify a variety of alternative solutions proving that this element had a very high impact on the overall view of the entire design tool. Mann and Dewulf (2001) illustrate a systematic creativity philosophy where the integration of TRIZ with other problem definition methods such as QFD and axiomatic design and creative thinking methods such as the six thinking hats™ are discussed. They demonstrate the flexibility that TRIZ offers and show the importance of it as an inventive problem solving approach substantiating the findings of the current studies. Techniques in TRIZ were not found in the ergonomics literature and therefore, literature on using TRIZ-based principles of design to identify design solutions to reduce work-related MSDs is novel.

As for limitations, again, lack of guidance was identified by the practitioners in the interview study and also by one of the practitioners that participated in the case studies. In addition, the time required to go through the list of principles was mentioned despite including an abridged list of the design principles. Again, no literature was found to facilitate further discussion of these issues pertaining to the use of the TRIZ-based design principles.

8.3.4. QFD matrix-based tool

The QFD matrix-based tool that was developed using Microsoft® Excel for this research facilitates communication among stakeholders in the design process by helping to record, manage and share design information (refer Chapter 4). The practitioner survey (refer Chapter 5), interview study (refer Chapter 6) and case studies (refer Chapter 7) showed ample evidence to determine that the QFD matrix-based tool managed to fulfil the expectations of the practitioners despite the limitations expressed. Its ability to record and visualise various information essential to design in a single interface would ensure sharing of design information and presenting it to the stakeholders in the design process as discussed in Section 8.2. As discussed in Section 8.3.2, Meyer and Avery (2009) illustrate the use of Microsoft® Excel as a qualitative analysis tool, supporting the feasibility the QFD matrix-based tool could have in the design process to manipulate and present design information.

Microsoft® Excel-based templates are commonly available on the internet to facilitate the QFD process (e.g. the QFD Institute). Furthermore, software to facilitate the QFD process is also available, for example, the commercial and non-commercial tools investigated by Herzwurm et al. (2003) as discussed previously. However, these are all based on the original house of quality matrix described in QFD literature and lacked flexibility to be easily adapted for the practitioners in the current study. In Herzwurm et al.'s study, Microsoft® Excel-based software was rated higher than the rest in terms of simple serviceability, fast learning and short response times. This was also highlighted by one of the practitioners in the interview study. In addition, the findings of the study by Herzwurm et al. (2003) show the majority of products do not facilitate multi-user options, analysis of user requirements, automatic evaluations and integration of other methods. This clearly indicates the limitations of current tools available to facilitate the

QFD process. The tool developed in the current research sought to address these limitations.

The main limitation identified regarding the Excel-based QFD tool was lack of guidance for the practitioners. The second most frequently mentioned limitation in the interview study was regarding the colour coding system to assess the feasibility of solutions, but all the practitioners in the case studies felt that the colour coding system was intuitive. The difficulty in formatting the Excel sheet was a usability issue identified by all of the practitioners in the case study. Another limitation was its inability to breakdown the matrix to facilitate effective presentation. This was pointed out by three of the practitioners in the interview study. Rawabdeh et al. (2001) states that many QFD practitioners use their own spreadsheets for supporting QFD process implementation and this is a weakness in available tools to facilitate the process. They also point out that existing QFD tools are not easy to use and take a long time to use. Another limitation they identify in existing software tools to facilitate QFD is the inability to incorporate all tables and matrices. As mentioned in Chapter 6, requirements to alleviate such limitations have been identified and discussed by Herzwurm et al. (1997). They identified 27 requirements from a study that elicited information from more than 60 German QFD practitioners. These will be further discussed in Section 8.7 under future work.

8.3.5. Solutions database

In the practitioner survey, the practitioner opinions with respect to the ability of current methods available to them to record the knowledge for improvements/future applications were divided and the importance attributed to such methods was high. This suggested a dearth of methods to record knowledge in the design process for future use. After presenting the solutions database, seven out of the eight practitioners that participated in the interview study believed that the database would be helpful in managing information. Two of the practitioners also stated that they would be able to use the saved information. Furthermore, two of the three practitioners that participated in the case studies and actually used the solutions database pointed out that it was a good and easy way to present design information and that a lot of information could be saved on one interface. The ratings of these practitioners for the performance of the solutions database as a method for recording knowledge for future use were also high. Haines et al. (2002) describes the inherent difficulties present in participatory ergonomics programmes. Perceived time and cost involved and the effort required to turn interventions into continuous improvement programmes are two of the issues discussed. The concept of the solutions database was presented to address these issues.

The Microsoft® Excel-based database tool helps to store the design information acquired from different projects, which could be sorted according to different criteria. The stored information could be conveniently used in other projects bypassing activities in the design process to save time. The design information also can be used to facilitate continuous improvement of products or processes that were designed in previous exercises. Databases have been used in design tools previously in research (e.g. Sivaloganathan et al., 1995). However, no literature was found on the use of databases in the context of this research.

8.4. Methodological considerations

The thesis claims that the design tool facilitates communication among the stakeholders of the design process. As mentioned in Section 8.2, findings from the practitioner studies suggest that the design tool can be used to present information that is required. Stakeholders in the design process consist of managers in the organisation, workers, ergonomists and practitioners of design such as engineers (Vink et al., 2008). Practitioners of design such as engineers constitute an essential element and according to Toft et al. (2003), they have a duty to ensure that the needs of the users are met. However, for this, design information needs to be effectively communicated to the relevant design practitioners. Unfortunately, in the practitioner studies described in this thesis, the sample consisted of only a small proportion of engineers and designers. Therefore, sufficient assessment of whether the design information that the tool presents was useful to all design practitioners was not possible.

Due to time constraints, practitioners of design were not specifically asked whether the design information presented was useful to them. For example, in the pipe installation study, the industrial engineer mentioned that the design information was presented to managers and the design team (refer Section 7.5.9), but unfortunately, the study did not extend to include the managers or members of the design team to understand the usefulness of this design information. This is a limitation of the research. Broberg (2007a) surveyed engineers in 20 Danish organisations and suggested that engineers are not always aware that they influence the work environments of other people. Furthermore, in a cross-sectional study of 36 engineering students by Toft et al. (2003), most welcomed the introduction of teaching ergonomics principles in their design practice. The majority of them also showed positive attitudes towards exposure to ergonomics training. This essentially means that design practitioners value ergonomics related information to design systems to fit the users, but it is unclear what information is exactly required to reduce workplace risk factors for developing MSDs. In the practitioner case studies, all the participants mentioned that the 'QFD-based matrix can be used to enter all necessary information' indicating the usefulness of the information presented. However, further research is essential to understand this more fully.

The design tool consisted of six features to encompass the design process, and accompanying guidance material was developed to facilitate the use and understanding of each of the features (refer Chapter 4). Thus, there were various useful methods suggested to facilitate practitioners in the design process. Validation of participatory approaches developed by researchers is considered to be a challenge because they use multi-factorial approaches that use different methods (Haines et al., 2002). To ensure the validity of the tool, techniques of evaluation were used at several stages to assess the design tool and the guidance material. The tool was initially developed using a comprehensive review of the literature and discussion process, and this itself can be considered as an evaluation (Pace, 2003).

As discussed earlier, QFD was identified as a potential method that can be used to enhance communication among the stakeholders of the design process using a literature review. Other methods such as axiomatic design (Suh, 1990), design function deployment (Sivaloganathan et al., 1995), trans-disciplinary design (Gumus et al., 2007) and product lifecycle management that could be used for this purpose were also considered and reviewed to identify the best method that could be utilised in the research (refer Section 2.7.7). However, this may involve researcher bias, and is identified as a limitation of the research. This emphasises the importance of conducting further research into identifying other ways of integrating the design process to enhance communication among the stakeholders of design.

Furthermore, the choice of tools related to engineering such as QFD to integrate the design process and TIRZ in the design tool to identify design solutions and more significantly the background of the researcher might have influenced the findings. This may have been the reason for emphasising engineering solutions to reduce the workplace risk factors for developing MSDs. This could be considered as a limitation of the research. Despite this, the tool was implemented and evaluated almost entirely by non-engineers minimising this bias. As mentioned by one practitioner in the interview study, psychosocial aspects can be included in the tool. In addition, aspects such as maintenance and project monitoring can be included, but further research is needed with regard to this.

The inclusion of a number of different tools and techniques in the design tool made it impossible to use a usability test approach for evaluation since the process of testing all elements would take a considerable time and effort. Therefore, expert evaluation was considered to be more appropriate (Rosenbaum, 1989; Armstrong et al., 2002). In line with this, a questionnaire study, interviews and case studies were performed to evaluate the design tool and its guidance material in different levels of detail. The online questionnaire survey of the practitioners (n= 32) elicited data pertinent to all of the elements of the design tool. However, questionnaires could be used only to conduct a superficial evaluation (Charlton, 2002b; Pace, 2003). In order to obtain a deeper understanding of the tool, a subset from the respondents to the questionnaire survey were interviewed (n= 8). As described in Chapter 6, a walkthrough approach was used and evaluations of individual components of the design tool were obtained. The best possible evaluation could be achieved is by employing field study techniques (Pace, 2003). Therefore, three practitioners evaluated the tool by implementing it in the industrial setting (refer Chapter 7). These were used as case studies to evaluate the design tool and its guidance material in-depth.

Since practitioners were considered to be familiar with techniques to identify risks and obtain user requirements, the tools and techniques included in the guidance material were not subjected to detailed evaluation compared to the other features. The literature supports this assumption (Dempsey et al., 2005; Williams and Haslam, 2006). Evaluation of these tools and techniques were only considered during the practitioner interview study (refer Chapter 6). This limited thorough evaluation of the suggested tools and techniques such as the interview guide, which were included in the design tool to facilitate practitioners in the process of identifying risks and user requirements.

When selecting organisations for the user requirements study, a purposive sampling procedure was used (Creswell, 2007). Unfortunately, only one organisation took part in the study. This may be considered as a barrier to claim validity of the results. However, in the subsequent practitioner case studies, individuals from different organisations took part, and for this, a stratified sampling procedure was used (Creswell, 2007). Similar findings to that of user requirements study were also obtained from these case studies, and this helped in cross-validating the findings of the user requirements study and the practitioner case studies.

In addition, the user requirements study was conducted in three case study areas selected purposefully. This included only three of the four work characteristics discussed in the literature (Denis et al., 2008): ‘variable environment and cyclic work task’, ‘stationary workstation and a varied work task’ and ‘variable environment and a varied work task’. As discussed in Section 3.6, one out of four combinations of work characteristics was absent from the study (i.e. stationary workstation and cyclic work task) and as such was a limitation of the research. The case studies conducted to evaluate the design tool addressed this missing combination of work characteristics. By coincidence, all of the three work tasks studied (i.e. stitching operation study, pipe installation study and the material loading study) involved a ‘stationary workstation and a cyclic work task’. The findings of the case studies also revealed that the workers were able to participate in identifying risks and requirements for design. Risks and user requirements were identified by the workers (users) in all of the three studies even though two different techniques were used (refer Table 7.3). Therefore, it is proposed that the research may be applied with confidence to all possible combinations of ‘workstation layout’ and ‘nature of task’ (${}^{2}C_{1} \times {}^{2}C_{1} = 4$) present in the industry.

In the user requirements study (refer Chapter 3), the author was instrumental in collecting the data, and this may be thought of as cause for bias in the findings. The effect on the results due to the presence of the researcher, the ‘Hawthorn effect’, is well documented (e.g. McKinnon, 1988; Wickström and Bendix, 2000; McCarney et al., 2007) and may result in reduced reliability and validity of the findings. However, attempts were made to minimise this effect by using different techniques: the data collection adopted semi-structured face-to-face interviews with both the workers and managers and observations. In the analysis, the data were triangulated and it was identified that the findings from the interviews with the workers corroborated with the observations. This is a strategy proposed in the literature to counter the limitations of using single methods to obtain data (Spielholz et al., 2001; Teschke et al., 2009). Moreover, similar findings were reported in the practitioner case studies (refer Chapter 7). Even though the practitioners used different techniques to collect data from the users (workers) without the presence of the author, the claim regarding worker knowledge and ability to participate in the design process to identify risks and user requirements also held true for the practitioner case studies. Similar to the findings of the user requirements study, risks and requirements for design were identified by the workers in the practitioner case studies although the researcher was not present when collecting such data from the workers.

Another consideration was the ability to generalise the findings of the research to a larger context. In the 'user requirements study', all the claims were made using a worker sample of only 22 from three case study areas (refer Chapter 3). This was discussed as a limitation of the study. However, similar claims could also be made regarding the practitioner case studies (refer Chapter 7). In the case studies, 28 workers took part in three different organisations in separate user requirements acquisition exercises increasing the validity of the findings of the user requirements study. Therefore, the claim regarding the ability of the workers to participate in the design process was altogether based on field studies in six different work environments and 50 workers. Worker involvement in participatory intervention programmes in various sectors is widely discussed in literature (e.g. Kuorinka and Patry, 1995; Rivilis et al., 2006; Vink and van Eijk, 2007). Furthermore, literature on methods such as QFD, axiomatic design and Kansai also emphasise usefulness of gathering requirements for design from the users themselves and rely on the users (in some instances referred to as customers) to imbue knowledge to solve problems encountered in the work environment (e.g. Akao, 1990; Kurniawan, 2002; Nagamachi, 1995). This also indicates the ability of the workers to participate in the design process and identify risks and requirements for design to reduce work-related MSDs providing plausible evidence to confirm the findings of the user requirements and the evaluation studies. However, more research is required in this regard and in different contexts.

The ability to generalise the findings of the research is diminished due to non-response in the practitioner survey. Although there was a 21% response rate with respect to the registered consultancies, the response rate was low for the online questionnaire (only 32 respondents from possible 1400 individuals or organisations). Refusal to respond and ineligibility to respond may be the most likely reasons for the non-response. The newsletter notice in the practitioner survey was a general invitation for participation and this too can be a reason for the low response rate. Therefore, it may be assumed that respondents were enthusiastic about the research and provided positive responses inducing a bias in results (Saunders et al., 2007). Unfortunately, the participants that were selected for the interview study and subsequently for the case studies were from the same sample and substantial errors in the results are therefore possible (Saunders et al., 2007). This may have magnified the bias of having a small sample (as discussed in Section 5.6.1) in the practitioner survey and resulted in obtaining mainly positive comments regarding the tool. Use of a different sampling strategy where the respondents are independent from the previous study could have minimised this bias. Therefore, it would be interesting to conduct further studies using different sampling strategies such as maximum variation, critical case, and confirming and disconfirming cases (Patton, 2002; Creswell, 2007) to obtain a more balanced view of the design tool.

Out of the total of 32 respondents, only 23 completed the entire questionnaire resulting in a completion ratio of 72%. Some of the practitioners mentioned that they are not involved in the entire design process to reduce work-related MSDs and hence completed only the relevant sections of the questionnaire. Another reason for this may be the effect of the online questionnaire layout design and the number of questions per screen as discussed by Toepoel et al. (2009). However, the guides to questionnaire design available at ‘SurveyMonkey’ (SurveyMonkey, 2008a; SurveyMonkey, 2008b) were used when designing the online questionnaire. Other literature on questionnaire design (e.g. Oppenheim, 1966; Saunders et al., 2007) was also referred when developing the questionnaire to ensure reliability of the elicited information.

8.5. Contribution to knowledge

The main contribution of this thesis is to emphasise the versatility of QFD and its ability to be modified to adapt to different applications. In this research, the QFD house of quality matrix approach was modified to develop a tool to facilitate communication among the stakeholders in the design process in order to help reduce work-related MSDs among the workers in the industry. In addition, the thesis contributes to existing knowledge by revealing that, being limited to the originally defined QFD would inhibit its potential and impede the possibility of it being applied to diverse scenarios conveniently. Therefore, looking into ways of modifying the QFD methodology to cater for specific needs without confining to the original form would help to address a variety of problems in industry.

QFD is identified as a flexible tool and various methods could be amalgamated with it to enhance its versatility. By exploiting this unique ability of QFD to integrate with other methods, this research contributes to the body of knowledge by proposing that, other tools and techniques could be used together with QFD to cater for the varied needs of industry. In this light, tools and techniques were identified to be included in the QFD matrix-based design tool with a focus on reducing work-related risk factors for developing MSDs. For example, a tool based on the constant comparative method and frequency ranking was used to help practitioners to prioritise the identified requirements for design. Then, design principles based on the TRIZ methodology, which has been successfully used with QFD in the past were integrated with the design tool to help practitioners identify creative solutions to the work-related problems and needs they identified. However, there can also be other tools and techniques that could help in the design process.

This research was an attempt to explore the potential of QFD as a basis to develop a design tool to help practitioners determine solutions for the user identified risks and requirements through effective communication and help manage work-related MSDs. The tool was developed with six features: ‘identify risks and obtain user requirements’; ‘prioritise the risks and user requirements’; ‘identify design solutions’; ‘select acceptable solutions’; ‘present risks and user requirements, and solutions’ and ‘record knowledge in a solution database for future use’. The features consisted of guidance material for practitioners. This tool intends to facilitate communication among the stakeholders of the design process to reduce work-related MSDs using a structured approach: a way of thinking that extends the knowledge beyond the realm of participatory processes discussed in the literature (e.g. Bobjer and Jansson, 1997; Haines et al., 2002; Vink et al., 2008) and is a unique contribution to the body of knowledge in ergonomics.

Another contribution of this research is to instil an understanding about simplifying, modifying and automating existing useful methods that are generally accepted as tedious and time consuming to be used effectively as part of a participatory design process. First, the QFD house of quality approach was simplified with a view to facilitate communication among stakeholders of the design process to reduce work-related MSDs as discussed in Chapter 4. Then, the constant comparative method (Glaser and Strauss, 1967; Lincoln and Guba, 1985) developed for applications in grounded theory was simplified, combined with frequency ranking, and the process was partially automated to make it convenient for the practitioners to obtain priorities for user identified risks and requirements for design. The constant comparative method has four defined stages for the process of analysis of qualitative data (Teddlie and Tashakkori, 2009). However, the prioritisation tool deployed only the first two of the four stages, ‘data categorisation and comparison’ and ‘integration of data’ to define themes. The rest was frequency ranking of themes. Finally, the forty principles of design defined in TRIZ (Terninko et al., 1998; Savransky, 2000; Rantanen and Domb, 2002) were simplified making the list shorter and easier to understand to make it useful as a practical tool for collective use by workers and practitioners in order to identify and suggest creative solutions to reduce workplace risk factors for developing MSDs.

Theory of inventive problem solving (TRIZ)-based design principles, which uses prompts to aid brainstorming as described in detail in Section 4.5.3, is an important technique within the design tool to help practitioners identify design solutions to the requirements for design. These prompts have been identified by observing the information and patterns present in millions of patents (Terninko et al., 1998; Savransky, 2000; Rantanen and Domb, 2002). This can be a useful resource in a participatory model to identify design solutions. Interestingly, this technique is not confined to providing solutions for product design, and could be used to provide solutions to any type of problem. For example, 'skip or quickly perform risky tasks' is relevant to an activity. As discussed earlier in Section 8.2, the design principles based on TRIZ could contribute towards physical design/specification of equipment/ workplaces/work tasks, design of job teams or work organisation and formulation of policies or strategies to help reduce work-related MSDs, which is a vital aspect of the participatory process (Haines et al., 2002). This aspect also encompasses a key element (i.e. idea generation) proposed in the 9-step participatory ergonomics process proposed by Vink et al. (2008). In general, practitioners that took part in the interviews and case studies highly appreciated the inclusion of the TRIZ-based principles in the design tool, and as discussed in Section 8.3.3, and their potential in identifying solutions to reduce workplace risk factors for developing MSDs is novel.

8.6. Relevance to industry

Feedback from the practitioners showed that the design tool (and guidance material) developed and presented in this thesis has potential in industry. It can be used collaboratively by practitioners such as ergonomists, health and safety personnel, designers and engineers alike to enhance communication in the design process. The included methods and tools also provide flexibility to be modified according to the varying needs of the practitioners in the industrial setting. In addition, the design tool provides a philosophical approach for the practitioners and the workers to collaboratively help reduce work-related MSDs through design concentrating not only on designing equipment, but also designing facilities, procedures and training that are instrumental in inducing workplace risks. According to a study reported by Williams and Haslam (2006), practitioners of ergonomics do not feel competent in planning, delivery and evaluation of interventions to deal with ergonomics problems as expected by the IEA. Therefore, the design tool presented in this thesis can contribute towards extending the horizons of the practitioners of ergonomics and design to help mitigate work-related MSDs.

The design tool was highly appreciated by the practitioners in the interview and the case studies (refer Sections 6.5.2 and 7.5.8). After use, all of the practitioners that took part in the case studies mentioned that they would continue to use it. All of them amalgamated the case studies with their company directives to improve selected work tasks in order to reduce the risk factors for developing MSDs. They indicated that the tool enabled them to present a clear picture of the design information and share this with other stakeholders in the design process such as managers and the members of the design team (refer Section 7.5.8). According to a survey of 680 engineers in 20 Danish enterprises by Broberg (2007a), engineers are not aware that they influence the work environment of other people and ergonomics had a low rating among engineers. This emphasises the importance of integrating engineers (a constituent of practitioners of design) with workers (users) and other practitioners.

Practitioners show reluctance in using structured design approaches that focus on transparency of design information and communication since they do not know how and when to use them and believe these methods hamper creativity (Green and Bonollo, 2002). However, when the practitioners were presented with the design tool, they appreciated it. The ergonomist in the stitching operations study, continued to use the tool to identify solutions to the remaining requirements for design identified during the case study and requested further assistance in using the tool in her organisation. The email sent by the ergonomist is shown in Appendix 8.1. The industrial engineer used the design tool to recommend design solutions to be incorporated in an aircraft structural component in order to reduce posture related risks that gave rise to MSD troubles. The design information obtained in this case study has been conveyed to the design team and they are considering these recommendations in future design of this structural component. This practitioner sent an evaluation of the design tool by email while conducting the study (Appendix 8.2). The occupational health technician also indicated during the interview held following the case study session that he would use the tool in future projects. He further said that appropriate changes would be made to the methods when required to make them better suit his applications. These strongly support the potential of the tool in the industrial setting.

8.7. Recommendations for future work

8.7.1. Further development of the design tool

As suggested throughout this thesis, QFD is a resource that can potentially be harnessed to help practitioners involved in the design process to reduce work-related MSDs. However, it cannot be considered as a panacea to every issue pertinent to communication in the design process. The design process is extremely complex and presents barriers to developing all encompassing tools to facilitate collaboration/ communication (Bruce et al., 1995). Therefore, it would be impossible to develop a tool that would solve all the shortcomings prevalent with respect to communication in the design process, especially within a limited time frame. Thus, the design tool described in this thesis needs to be further developed, taking on board the limitations identified and made more comprehensive. This section will shed light on the directions for future research for the effective use of the tool and its development.

The three studies conducted to evaluate the design tool (refer Chapters 5, 6 and 7) provided insight into specific improvements required in the tool. The needs of the practitioners from the survey (refer Section 5.5.5), views from the practitioner interviews (refer Sections 6.5.2 - 6.5.9) and case studies (refer Section 7.5.8) were compiled together to identify a list of recommendations for future work. The main themes that emerged this analysis are discussed below.

All of the participants in the practitioner interviews and the case studies were concerned about the inadequacy of the guidance mentioned and suggested that a simple step-by-step approach was required (e.g. refer Table 6.2 and Table 7.8). This was a concern expressed with regard to every feature of the design tool. Therefore, information needs to be simplified and separate guidelines need to be developed to support the selection and use of tools and techniques within the guidance material. One of the participants in the practitioner interview study suggested the feasibility of using flow charts to provide succinct guidelines. Flow charts and structure charts are extensively used in the field of software engineering with success to explain processes and choices within such processes (e.g. Kendall and Kendall, 1999). Thus, research is required to identify suitable methods such as those used in software engineering to develop guidance to facilitate practitioners to understand and use all elements of the design tool effectively throughout the design process.

One respondent reported in the practitioner survey that simple, quick and easy to use tools that demand minimal time and resources must be provided in order to reduce the time required and keep people motivated. Attempts were made to have such tools available throughout the design tool and this was acknowledged by the practitioners. For instance, the majority stated that the feature for identifying risks and user requirements has a set of tools that could be readily used. In spite of this, in the interview study, half of the practitioners mentioned that ‘the entire process is long and may take a lot of time’. These limitations can be addressed by automating procedures in the tool. In addition, three of the practitioners stated that it would be good to have the capability to breakdown the QFD-based matrix into sections when necessary. In the practitioner case studies, issues such as formatting of the matrix and having to keep several windows open at a given time were also mentioned.

Automation of the process was a suggestion that came up regularly in the evaluation studies. For instance, six of the participants in the practitioner interview study and all of the participants at different stages of the practitioner case studies pointed out that automation of the process could be used to reduce repeated actions and hence the time required to go through the process. Therefore, research into the ways of automating the process is recommended.

The Microsoft® Office-based tool could be considered as a first step towards developing an automated system to facilitate communication in the design process. A process such as this could be automated using different approaches: developing software to operate on stand-alone computers, network computers or online, and there are advantages and disadvantages in using these approaches (Kendall and Kendall, 1999; Wang et al., 2002). Integration of Microsoft® Office applications using Visual Basic® scripting is a software option that can be used to automate the design tool if it is developed as a stand-alone tool or an intranet based tool. For instance, Deacon et al. (2004) used scripting to integrate Microsoft® Excel and Word with a database-supported back end to automatically record student responses and automate common procedures that improved usability and feedback in a learning environment. This course of action is preferred for future development of the tool since the practitioners appreciated the use of Microsoft® Office in this research. However, XML programming, which is widely used in industry, is preferable if the tool is to be developed as an online peer-to-peer data management and integration approach (Abiteboul et al., 2002). The most suitable approach needs to be selected by weighing the pros and cons of each with respect to the requirements. For example, two of the participants in the practitioner interview study stated that it would be good to have an online tool that could be updated collaboratively, and requirements such as these need to be taken into account when determining further development. Further research is recommended in this direction.

Requirements for a software tool can be identified from the practitioner interview study and the case studies. For example, three of the practitioners in the interview study further stated that it is good to be able to update the solutions database collaboratively and one stated that the ability to generate reports would be helpful. The provision to filter data according to different criteria was mentioned by one of the three practitioners in the case studies. Furthermore, drop-down menus were appreciated by two of the three practitioners. Such requirements need to be taken into account when deciding on an approach to develop an automated QFD-based design tool. These requirements can be supplemented with the research findings from similar research for example, the 27 requirements for software development to facilitate the QFD process by Herzwurm et al. (1997). There have also been previous attempts to develop software tools to facilitate the QFD process (Rawabdeh et al., 2001; Herzwurm et al., 2003) and such experiences can be helpful in developing an automated tool. Wang et al. (2002) state that no automated tools were found that facilitate the initial phase of conceptual design due to the complex nature of the process. According to them, different stakeholders with conflicting requirements such as users, designers and engineers make the design process complex. Moreover, the design tool elaborated on in this thesis does not use the original house of quality QFD matrices unlike the QFD software tool described by Rawabdeh et al. (2001). Developing a software tool that incorporates the approach described in this thesis presents a fertile domain for further research.

A requirement in relation to the feature for 'identifying risks and obtaining user requirements' of the design tool was the addition of other sources of information. However, if individual methods and techniques are added to the guidance material, it has to be carried out without cluttering it. Furthermore, additional methods and techniques that would potentially help the practitioners involved in the design process need to be identified or developed. For instance, one of the practitioners in the interview study mentioned that the tool needs to have provision to collect information on psycho-social factors. Research on methods to assess risk factors (e.g. David, 2005; Dempsey et al., 2005) and compilations of methods published by different authors (e.g. Wilson and Corlett, 1990; Stanton et al., 2005) can be instrumental in determining appropriate methods to be listed. Difficulty in going through the themes and formatting the tool for prioritisation were also identified as limitations. Therefore, the tools within the guidance material need to be evaluated further and refined accordingly in order to alleviate such shortcomings.

The design principles also need to be refined in order to facilitate the practitioners more efficiently. Although it was identified as an important and very useful tool by all the participants that took part in the interview and the case studies, practitioners had to be assisted to find design solutions. One of the practitioners in the case studies mentioned that some practitioners may not be able to come up with solutions and another was concerned about having too many solutions making it difficult to decide which ones to use. 'Descriptions of design principles can be made more MSD related' was another suggestion that was mentioned. These findings show that more work in this regard is necessary in order to develop this feature of the design tool further.

Although participants in the practitioner case studies found no difficulty in assigning colours to the solutions based on their feasibility to put into practice, half of these interviewed mentioned that the colour coding system needs to be consistent and intuitive. Previous research conducted in relation to colour coding, also referred to as colour systems pertinent to warning and control design (Lehto, 2000) and design feasibility assessment (Akao, 1990; Suh, 1990; Rantanen and Domb, 2002) need to be further reviewed in order to establish a more robust technique for the assessment of feasibility of design solutions.

Practitioners that participated in the evaluation studies were instrumental in identifying additional elements that could be integrated into the design tool. These were considered beyond the scope of the current research mainly due to time and cost constraints. The main elements that were identified for future development are as follows:

- Provision to integrate/include photographs, sketches and cost/benefit information in the QFD-based matrix, i.e. number of affected workers and financial savings.
- Prompts to include material and time related information in the QFD-based matrix.
- Additional fields could further enrich the solutions database. For example, another column (i.e. field) in the solutions database to include the context and the cost of solutions. The ability to filter data according to different criteria and record the outcomes of projects to provide feedback would also be useful.
- Inclusion of criteria for ensuring maintainability and future-proofing. These requirements encompass project monitoring and evaluation processes.

8.7.2. Future research needed

QFD was selected to be used in this research purely based on a literature review (refer Section 2.7 and 4.2). This was discussed as a limitation of the research in Section 8.4. Thus, it would be interesting to carry out comparative studies on different methods that could potentially be used to integrate the design process. These studies could be used to evaluate the performance of different methods such as axiomatic design and design function deployment against each other. Comparative studies may lead to the selection of methods based on rigorous criteria, which may be hidden to the researcher when the selection is based on a literature review. Charlton (2002a) elaborates on a methodology for selecting tools for human factors testing and evaluation of situation (i.e. what elements in the environment, stimuli, setting events, system functions or goals), individual (i.e. who is using), task (i.e. how is it used) and effect (i.e. factors of success or failure) is advocated. This strategy could be used to evaluate the other available design methods along with QFD. These evaluation studies preferably need to be conducted by different researchers to reduce researcher bias.

Testing the design tool in a limited number of environments by a small number of practitioners is another limitation of the research. Therefore, further tests need to be carried out in different work situations by practitioners with different capabilities and limitations in terms of their education and training. As previously discussed, only one out of four combinations of work characteristics discussed in the literature (Denis et al., 2008) was considered in the case studies (i.e. stationary workstation and cyclic work task). In addition, research suggests that there are practitioners with different educational backgrounds and varied levels of experience (Dempsey et al., 2005; Williams and Haslam, 2006) supporting the findings of the practitioner survey. These suggest that the tests to evaluate the design tool have to encompass the various work characteristics presented in the literature (Denis et al., 2008): ‘variable environment and cyclic work task’, ‘stationary workstation and a varied work task’ and ‘variable environment and a varied work task’ and ‘stationary workstation and cyclic work task’. These also need to include different sectors of practitioners in industry such as ergonomists, occupational health personnel, managers, engineers and psychologists that are involved in reducing of work-related MSDs. This would enable generalisation of the test results.

In the practitioner survey, the ability to share information effectively with cross-functional teams was identified as a requirement of the design tool. In order to ensure this, a systems approach that can maintain or manage single devoted tools such as the techniques for risk assessment was advocated recognising that almost all factors will interact (refer Section 5.5.5). The QFD-based design tool follows the systems approach, and the practitioner interview and case studies largely showed that the tool can be used to present essential design information. Despite this, as recognised earlier (refer Section 8.5), research is required to first assess whether the design information presented in the tool is useful to design practitioners such as designers and engineers.

Broberg (2007a) reports that ergonomics related practitioners need to acknowledge that engineers are widely different and that they have different backgrounds and sensitivity towards ergonomics depending on their engineering domain, tasks, organizational position and the industrial branch of their organization. Therefore, presenting design information becomes a complex issue. Conversely, Bennett (1997) cites from a publication by Weick (1987) that the differences among participants serve to enrich the participatory process, and variety in areas of expertise, academic background and collective experience can substantiate the outcome. Therefore, as an extension to the current research, further studies with all the relevant stakeholders of the design process are proposed to determine the usefulness and effectiveness of the inputs and outputs of the design tool and to identify what additional design information is required.

Furthermore, in the pipe installation case study, the workers collectively identified solutions to problems, facilitated by the design principles from the tool as part of a focus group session (refer Section 7.5.5). This indicates that workers are able to actively participate in identifying design solutions. Therefore, it is plausible to believe that the workers can effectively take part throughout the design process to communicate design information to the practitioners to help minimise MSDs. Designers tend to interpret user needs as perceived representations of the use of the new devices and these play a vital role in the choice of solution (Darses and Wolff, 2006). These authors further state that the perceived representations of the user needs could be changed by diversifying the types of meetings with the users facilitated by project leaders, for example, ergonomists. Baecker et al. (2000) studied three cases of usability assessment in relation to software engineering and suggest the gap between what users know and what they need to know needs to be reduced in order to reduce the complexity of software applications. These also signify the requirement for further research in this regard to ascertain worker ability to take part in identifying design solutions in order to influence design decisions that in turn affect the workers (users) themselves. In addition, it arouses interest to research into ways of increasing worker capacity to involve them more in the design process and elicit more information.

Another area, which needs attention, is the standards, guidelines and regulations related to ergonomics and design to reduce work-related MSDs. This could be carried out with the integration of a database, if a software tool is developed. However, sources of information need to be identified in order to populate the database. At present, information on standards, guidelines and regulations are available from a plethora of sources such as BSI, European standardisation institute, ANSI, HSE, OSHA, handbooks and journals (Lehto, 2000). Practitioners would be discouraged to access such information due to time demands in industry. In addition, this information gets updated regularly and this needs to be taken into consideration when improving the tool. For this, an information system with a central database that could be updated collectively by practitioners and researchers is advocated (Oulid-Aissa et al., 1998; Hoffer et al., 2009). DSTAN, the UK defence standardisation web portal is an attempt towards achieving this (refer www.dstan. gov.uk). In spite of this, more research on this is recommended to encompass the ability to collectively update and retrieve information from the database.

8.7.3. Dissemination plan

As discussed in Section 2.7.7, an opportunity exists for tools to facilitate the conceptual design stage and the impact of design decisions at this stage is high (Wang et al., 2002). Graves (1992) discusses the importance of integrating ergonomics in engineering design. Design tools and methods available in the process of design is numerous and for many practicing designers it has become unclear when and how to use them, and there is a culture that believes these methods and tools impede creativity (Green and Bonollo, 2002). Thus, practitioners show a propensity to reject such systematic methods and tools. Furthermore, the literature reveals that practitioners that were not taught design methods fail to incorporate them into professional practice, and it is desirable to include these aspects in design student training (Green and Bonollo, 2004). Interestingly, engineering teaching professionals appreciated the inclusion of principles of ergonomics in design practice and supported inclusion of ergonomics principles in the undergraduate engineering curriculum (Toft et al., 2003). As discussed in Section 2.7.7, an opportunity exists for tools to facilitate the conceptual design stage and the impact of design decisions at this stage is high (Wang et al., 2002). Graves (1992) discusses the importance of integrating ergonomics in engineering design. Design tools and methods available in the process of design are numerous and for many practicing designers it has become unclear when and how to use them, and there is a culture that believes these methods and tools impede creativity (Green and Bonollo, 2002). Thus, practitioners show a propensity to reject such systematic methods and tools. Furthermore, the literature reveals that practitioners that were not taught design methods fail to incorporate them into professional practice, and it is desirable to include these aspects in design student training (Green and Bonollo, 2004). Interestingly, engineering teaching professionals appreciated the inclusion of principles of ergonomics in design practice and supported the inclusion of ergonomics principles in the undergraduate engineering curriculum (Toft et al., 2003). In addition, Williams and Haslam (2006) conducted a study with 183 ergonomics professionals and identified that they were less competent at planning, delivery and evaluation of interventions to deal with ergonomics problems.

Therefore, it would be important to disseminate the design tool and knowledge acquired by this research at large through the undergraduate and postgraduate programmes for not only engineering but also ergonomics. Innovative teaching programmes are discussed in the literature. For example, three traditional independent modules; manufacturing, ergonomics and simulation were integrated into teaching industrial engineering have been carried out and these experiences have been published (e.g. Carrano et al., 2003). Such experiences can be utilised in developing curricula for the undergraduates. This would help widen the repertoire of both the engineering and ergonomics community. The design tool can also be disseminated through continuous professional development (CPD) programmes to the practitioner community. Another strategy to distribute knowledge is to present and publish the design tool and findings of the research in conferences, journals and other media such as newsletters that are distributed among the practitioners that are involved in design and ergonomics.

8.8. Conclusions

The conclusions of this research are listed according to the objectives of the thesis.

This research showed that the workers can successfully contribute in the design process and make suggestions for design to reduce work-related MSDs. All workers specified requirements for design, but they were inclined to identify risks and specify requirements for design pertinent to more frequently performed task elements that pose higher MSD risk (assessed using the NMQ, REBA and WBD scales). In addition, workers tend to specify more risks and requirements for task elements that involved manual handling rather than for posture-related task elements. User-identified risks and requirements together with practitioner observations could be used to obtain a comprehensive picture of the design requirements to reduce workplace risk factors for developing MSDs. These findings also corroborate with other research.

The design tool that was developed based on the QFD house quality approach could potentially help to enhance communication among stakeholders in the design process. This tool is an attempt towards delivering a way of thinking, a philosophy, for the practitioners to help reduce work-related MSDs by communicating design information from the users (workers) to practitioners of design. It included six features: (1) identifying risks and obtaining user requirements; (2) prioritising the risks and user requirements; (3) identifying design solutions; (4) selecting acceptable solutions; (5) presentation of risks and user requirements, and solutions; (6) recording knowledge in a solutions database for future use. Useful methods were integrated with the guidance material to facilitate practitioners in carrying out the tasks within the six features of the tool and guide them through the design process. For example, these included: design principles (based on systematic inventive problem solving-TRIZ) to help identify design solutions and Microsoft® Excel tools to help record, manage and present design information.

The practitioner survey showed that the tool has potential in industry. In the evaluation studies, all of the practitioners appreciated the design tool and the supplementary methods included in the guidance material. Half of the practitioners that took part in the interview study mentioned that the tool would help collaboration/communication with others. Half of the practitioners also said that the tool would guide the practitioners through the process. These findings were confirmed by the case studies. All of the practitioners reported that the tool could be used to manage design information, and visualise MSD risks in the workplace and possible solutions before pursuing them, thus helping to share design information.

The design tool was not without limitations, the main one being the inadequacy of guidance to effectively help the practitioners understand the overall process and procedures within the tool. Another salient limitation pointed out by half of the practitioners that participated in the interview study was time taken to go through the entire process. The same finding was revealed by all of the practitioners in the case studies. The limitations identified helped to draw recommendations for future research. The development of better guidance has already been mentioned, but the other main suggestion was the automation of the procedures to reduce the time requirement to complete the process. Literature indicates that the future development of the design tool and the guidance material is possible.

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Appendices

Appendix 2.1: Other terms used to describe MSDs

Term	Definition
Ailment	• A mild illness or injury, especially a persistent one (Encarta dictionary, 2007).
Injury	• A biological event representing the impact of an environmental alteration on an individual. Such alterations are of numerous types and intensities and may range from invasion by biological agents such as viruses or bacteria, through exposure to toxic substances or various forms of radiant energy, to physical forces, including those capable of damaging musculoskeletal structures. The extent of physical injury after such exposure varies widely depending on the intensity of the adverse event, the duration of exposure to it, and the characteristics of the injured individual (National Research Council and Institute of Medicine, 2001) • Mechanical disruption of tissues resulting in pain (Kumar, 2001)
Illness or sickness and disease	• An illness or sickness is showing symptoms, other discomforts, dysfunctionality, fear and social impacts. On the one hand, a disease is a biological event characterized usually but not invariably by definable and objective change or an abnormality explored through a test or an examination. Disease and illness are usually present together and in related fashion, but this is not inevitably the case. Thus, it is possible to be ill in the absence of objective change (migraine headache is a good example), and it is possible to have objective disease without being ill (for example, a small lung tumour evident on a chest X-ray that has not yet produced any symptoms (National research council and Institute of Medicine, 2001)
Disorder	• A multifactor problem involving physical, psychological and organisational risks that do not essentially relate to injury or illness (WHO, 1985- cited by Amell and Kumar 2001)
Syndrome	• A group of signs and symptoms that together is characteristic or indicative of a disease or a disorder (Encarta, 2007).

Term	Definition
	• A group of symptoms which consistently occur together or a characteristic combination of opinions, emotions, or behaviour (Soanes and Hawker, 2007) • A group or pattern of symptoms that together are indicative of a particular disease, disorder or condition (Wordsmyth, 2007) • The syndrome is characterised by a disturbance in the balance between load and physical capacity, preceded by activities that involve, repeated movements or prolonged periods spent with one or more of the relevant body parts in a fixed position. RSI is always caused by a combination of factors (Health Council of the Netherlands, 2000)
Pain	• Pain can have no precise definition because only the suffering individual perceives it. Pain receptors are widely distributed in the tissues of the body and appear to be stimulated either by strong mechanical deformation, by extremes of hot or cold, or by various chemical substances liberated by inflammation or other processes. Pain is transmitted through peripheral nerves to the spinal cord and to the brain. Various responses are elicited, through a variety of neural connections involving the spinal cord as well as descending pathways from the brain. Some of these are reflex in nature and others involve complex reactions that vary widely (National Research Council and Institute of Medicine, 2001)

Appendix 3.1: Participant information sheet (User requirements study)

This study is carried out as postgraduate research in the Department of Human Sciences, Loughborough University. The aim of this research is to help engineers in designing user friendly equipment and to redesign workplaces to suit the workers. It is hoped that it will benefit both employers and employees in the industry.

People do various tasks regularly at work. However, some work tasks give rise to aches and pains. The reason for this may be unsuitable work practices or use of unsuitable equipment during work. The solution for this is designing user friendly tasks and equipment. But, if the engineers do not understand your needs, they will be unable to design the right equipment to help your work. You may well know what is already available to you, and what you need to help your work and to prevent aches and pains. We need your help in finding these user needs to help the design engineers' job.

Thank you very much for agreeing to participate in this unique study. The information that you give me is invaluable. You will be interviewed and your work tasks will be observed. The interview will need about 20 minutes of your time. The information you give will be treated in strict confidence.

At the end of the interview please indicate whether you will be interested in participating in future studies as well. Please feel free to contact us at any time if you have any questions (contact details are given below). I look forward to working with you.

Himan K.G. Punchihewa

Contact information

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Appendix 3.2: Consent form

Research title: User views on features to include to help practitioners reduce work-related MSDs

Informed Consent Form

(to be completed after Participant Information Sheet is read)

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethical Advisory Committee.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence.

I agree to participate in this study.

Your name ______________________________

Your signature ______________________________

Signature of investigator ______________________________

Date ______________________________

Department of Human Sciences, Loughborough University, Loughborough, LE11 3TU

Appendix 3.3: Interview guide (Workers)

User requirements study

This research examines the potential of an established design tool as a means of designing better jobs and equipment for workers in order to minimise musculoskeletal troubles. This interview mainly asks you about your job and your suggestions to improve your job. It takes approximately 20 minutes. There are no right or wrong answers, so please be as honest as possible. All responses will remain confidential. Any information indicating your identity will be removed and will not be linked to your responses. The information you provide will be valuable for the industrial sector.

Interview: Workers

Reference number W DD/MM/YYYY/OR/__

Date DD/MM/YYYY

Investigators

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Himan K.G. Punchihewa	Diane E. Gyi
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Department of Human Sciences, Loughborough University, Loughborough, LE11 3TU

Notes:

Section 1: Personal information

1. What is your age? (☑)

Age (yrs.) 16-25 26-35 36-45 46-55 56-65 >65

☐ ☐ ☐ ☐ ☐ ☐

2. What is your gender? (☑)

Male (1) ☐ Female (2) ☐

3. What is your height?

	cm	**OR**		ft		inches

4. What is your weight?

	kg	**OR**		stones		pounds

5. What is your ethnic background? (☑)

Ethnic origin	White	Black	Black British	South Asian	East Asian	Asian British	Mixed
	☐	☐	☐	☐	☐	☐	☐

Unknown ☐

Other (please specify)

Section 2: Job information

1. What is your job title?

2. How long have you worked for your current employer?

3. Are you working in this organisation full time or part time? (☑)

Full time ☐
Part time ☐

4. Which one of the following most appropriately describes your work time? (☑)

a Fixed hours - day shift only ☐
b Fixed hours - night shift only ☐
c Flexible hours - day or night shift ☐
d Other (please explain)

5. Reflect on a typical work day. Can you please explain the work tasks that you perform regularly throughout the day at the workplace and how many hours are you assigned for each task?

Work activity	Hours a day

6. How many hours do you work in this capacity in a typical week? ______ Hours

7. How many years have you been working as a [Job title] and what are your other job experiences?

Section 3: Awareness of MSDs

1. Are you concerned about developing aches and pains from your work? (☑)

Yes (1) ☐ No (2) ☐

2. Do you think changes should be made to reduce the risk of aches and pains from your work in the next 6 months? (☑)

Yes (1) ☐ No (2) ☐

3. Do you think changes should be made in the next month or two? (☑)

Yes (1) ☐ No (2) ☐

4. Have you got any **suggestions for changes** that would reduce the aches, pains, discomfort, numbness or tingling from your work?

5. Has your **employer made any changes** to reduce the risk of aches and pains from your work? (☑)

Yes (1) ☐ No (2) ☐

If **yes**, Please describe what those changes were?

6. Are you **doing or have you done** anything to reduce the risk? (☑)

Yes (1) ☐ No (2) ☐

If **yes**, please describe what you have done?

7. How long ago did you make these changes?

_______ Yrs / Mths / Wks (Circle the unit as appropriate)

8. **If more than 6 months ago**, do you intend to do anything more? (☑)

Yes (1) ☐ No (2) ☐

If **yes**, please describe.

Section 4: User requirements

1. Consider your main work task discussed previously.

Note the task

From here onwards, we'll focus on your main work task and the equipment use as part of your job.
[Note: Main work task refers to any one of: seated, standing and mobile work tasks]

2. Thinking particularly about preventing aches and pains, what are the **poor features** in the design of this (equipment, shelves or gadgets etc.)? Tell me what those poor features are according to your experience? In other words, what are the **things you dislike** about it?
[Guide the worker through different elements of the work tasks that the worker performs]

3. Thinking particularly about preventing aches and pains, what are the **good features** in the design of this (equipment, shelves or gadgets etc.)? Tell me what those good features are according to your experience? In other words, what are the **things you like** about it?
[Guide the worker through different elements of the work tasks that the worker performs]

4. Do you use methods of your own (i.e. methods that you have found or invented) to make your main work task easier (in terms of preventing aches and pains) such as any work practices or use of any additional tools?

5. Imagine that I am a designer and that you (as an experienced worker) are given the responsibility of suggesting requirements for your main work task on behalf of your fellow workers. What features would you say to me are important in the design to eliminate work strain. For example aches, pains, discomfort, numbness, tingling or difficulty from your work task?

6. How often do you get work breaks during work and how long are they?
How do you spend your work break?

7. If you were given the opportunity, how would you rearrange the work breaks to reduce tiredness?

Section 5: Musculoskeletal concerns

1. Please answer all the questions in the first column (☑). If yes, please answer the questions in the other three columns for that body area.

Have you at any time in the last 12 months had trouble (such as aches, pains, discomfort, numbness or tingling) in:	Have you had any trouble during the **last 7 days**?	Have you at any time in the **last 12 months** been prevented from carrying out any of your normal activities (e.g. job, housework, sport) because of this trouble?	In your opinion, do you think this trouble is actively **related to the work you do**?	In your opinion, what are the main **reasons** for this problem?
1. Neck No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	
2. Shoulders No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	
3. Upper arms No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	
4. Elbows No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	
5. Forearms No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	
6. Wrists No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	

Have you at any time in the last 12 months had trouble (such as aches, pains, discomfort, numbness or tingling) in:	Have you had any trouble during the **last 7 days**?	Have you at any time in the **last 12 months** been prevented from carrying out any of your normal activities (e.g. job, housework, sport) because of this trouble?	In your opinion, do you think this trouble is actively **related to the work you do**?	In your opinion, what are the main **reasons** for this problem?
7. Hands No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	
8. Fingers No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	
9. Upper/Middle back No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	
10. Lower back No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	
11. Hips or buttocks No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	
11. Upper legs No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	
13. Knees No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	

Have you at any time in the last 12 months had trouble (such as aches, pains, discomfort, numbness or tingling) in:	Have you had any trouble during the **last 7 days**?	Have you at any time in the **last 12 months** been prevented from carrying out any of your normal activities (e.g. job, housework, sport) because of this trouble?	In your opinion, do you think this trouble is actively **related to the work you do**?	In your opinion, what are the main **reasons** for this problem?
14. Lower legs No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	
15. Ankles or feet No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	No Yes 2 ☐ 1 ☐	

Section 6: Involvement in the task design decision

1. The company has to design new tasks, order new equipment from time to time. Do you get the chance to feedback your views on any equipment or task etc.? (☑)

Yes (1) ☐ No (2) ☐

If **no**, please answer question 4 onwards. If **yes**, please answer questions 2 and 3 also.

2. What exactly is your involvement in the job and/or equipment specification or ordering process?

3. Rate on the 1-9 scale, **your impact** on the overall decision according to your understanding. (☑)

No impact at all ——————→ Very high impact

1	2	3	4	5	6	7	8	9
☐	☐	☐	☐	☐	☐	☐	☐	☐

4. According to your knowledge, who gets involved in obtaining specifications of jobs and/or equipment for your organisation? Name the people who get involved.

Thank you so much for participating in this study and hope you would help in the future too.

Department of Human Sciences, Loughborough University. Loughborough, LE11 3TU

Appendix 3.4: Observations proforma (Workers)

User requirements study

This research examines the potential of an established design tool as a means of designing better jobs and equipment for workers in order to minimise musculoskeletal troubles. These observations collect data to improve your job. It takes approximately 1 hour. All observations will remain confidential. Any information indicating your identity will be removed and will not be linked to the observations. The information you provide will be valuable for the industrial sector.

Observations

Reference number	W DD/MM/YYYY/OR/__
Date	DD/MM/YYYY

Investigators

Researcher	Supervisor
Himan K.G. Punchihewa	Diane E. Gyi
Email: H.K.G.Punchihewa@lboro.ac.uk	Email: D.E.Gyi@lboro.ac.uk
Tel : 01509 223019	Tel : 01509 223043
Mob: 07956 656761	

Department of Human Sciences, Loughborough University, Loughborough, Leics. LE11 3TU

Notes:

Work element recording checklist

A. Dimensions

Element		Comment
1.	Has a tall man enough room?	
2.	Can a petite woman reach everything?	
3.	Is the work within normal reach of arms or legs?	
4.	Has the worker been provided a good chair for seated work? (height, seat, back)	
5.	Is the work plane correct for seated work?	
6.	Is an armrest necessary? If so, does the chair have arm rests? (location, shape, position, material)	
7.	Is a footrest required? If so, does the worker use a footrest? (height, dimensions, shape, slope)	
8.	Can the worker stand stable if it is standing work?	
9.	Is the work plane correct for standing work?	
10.	Is it possible to vary the working posture?	
11.	Is there sufficient space for knees and feet?	
12.	Is the distance between the eyes and work correct?	
13.	Does the work require repeated similar movements?	
14.	Are heavy loads being carried in mobile work?	
15.	Are loads carried continuously?	

B. Forces

Element		Comment
1.	Are static loads avoided as far as possible?	

2.	Are repetitive loads eliminated as far as possible?	
3.	Are vices, jigs, conveyor belts, etc., used wherever possible?	
4.	Where protracted loading of a muscle is unavoidable, what are the typical maximum loads encountered?	
5.	Are technical sources of power employed where necessary?	
6.	Has the number of groups of muscles employed been reduced to the minimum with the aid of counter support?	
7.	Are torques around the axis of the body avoided as far as possible?	
8.	Is the direction of motion as correct as possible in relation to the amount of force required?	
9.	Are loads lifted and carried correctly, and are they not too heavy?	

Work element recording form

	1	2	3	4
Purpose	What is achieved?	What would happen if it weren't done?	What could be done and still meet the requirements?	What should be done?
Place	Where is it done?	Disadvantages of doing it there:	Where else could it be done? Advantages of doing it elsewhere:	Where should it be done?
Sequence	When is it done? After:	Disadvantages of doing it then:	Advantages of doing it sooner: Advantages of doing it later:	When should it be done?
Person	Who does it?	Why that person?	List others who could do it.	Who should do it?
Means	What equipment and methods are used? Equipment: Methods:	Disadvantages of equipment: Methods:	How else could it be done? Advantages:	How should it be done?

Direct observations: User requirements

1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Appendix 3.5: REBA proforma

User requirements study

This research examines the potential of an established design tool as a means of designing better jobs and equipment for workers in order to minimise musculoskeletal troubles. These recordings collect data to improve your job. All recordings will remain confidential. Any information indicating your identity will be removed and will not be linked to the recordings. The information you provide will be valuable for all sectors of the industry.

REBA assessment

Reference number	W DD/MM/YYYY/OR/__
Date	DD/MM/YYYY

Investigators

Researcher	Supervisor
Himan K.G. Punchihewa	Diane E. Gyi
Email: H.K.G.Punchihewa@lboro.ac.uk	Email: D.E.Gyi@lboro.ac.uk
Tel : 01509 223019	Tel : 01509 223043
Mob: 07956 656761	

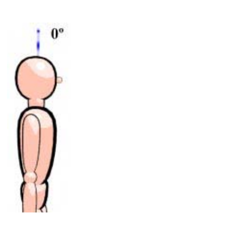
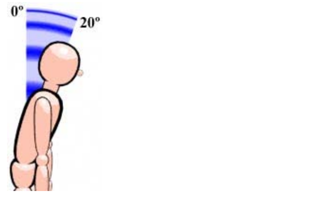
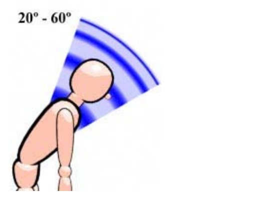
Department of Human Sciences, Loughborough University, Loughborough, Leics. LE11 3TU

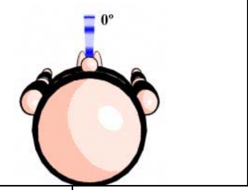
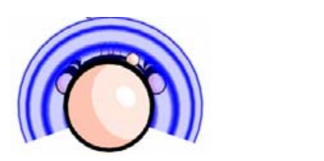
Notes:

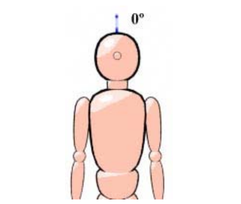
REBA recording form template

Task duration:
Task description:
Recorded by:

Trunk		
Movement	Score	Change score: +1 if twisting or side flexed
Upright	1	
$0^0 – 20^0$ flexion $0^0 – 20^0$ extension	2	
$20^0 – 60^0$ flexion $> 20^0$ extension	3	
$> 60^0$ flexion	4	

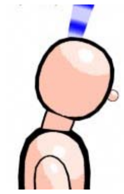
Trunk				
		 or extension	 or extension	
Muscle Use	☐ Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute			

Trunk Twist		
		
Muscle Use	☐ Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute	

Trunk Side-bend		
		
Muscle Use	☐ Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute	

Neck		
Movement	Score	Change score:
$0^0 – 20^0$ flexion	1	+1 if twisting or side flexed
$> 20^0$ flexion or in extension	2	

Neck

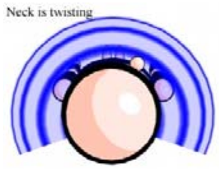


0^0 - 20^0

$> 20^0$

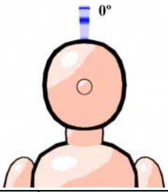
Muscle Use	☐ Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute

Neck Twist



Muscle Use	☐ Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute

Neck Side-bend



Muscle Use	☐ Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute

Legs		
Position	Score	Change score:
Bilateral weight bearing, walking or sitting	1	+1 if knee(s) between 30^0 and 60^0 flexion
Unilateral weight bearing, featherweight bearing or an unstable posture	2	+2 if knee(s) are $> 60^0$ flexion (not for sitting)

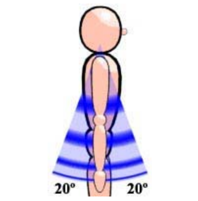
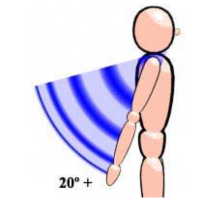
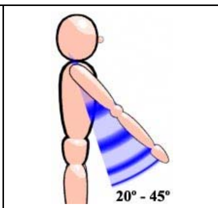
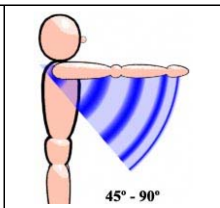
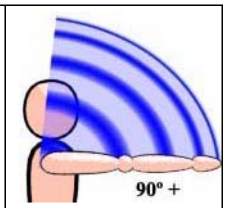
Legs

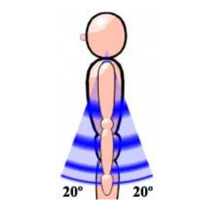
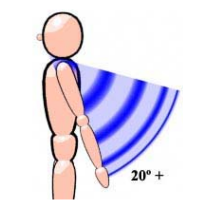
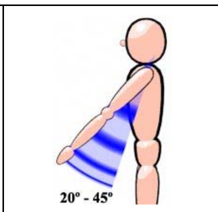
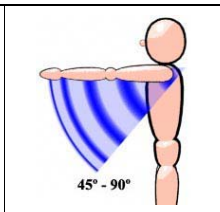
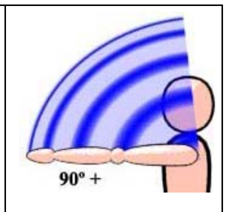
Bilateral weight bearing, walking or sitting.

Unilateral weight bearing, featherweight bearing or an unstable posture

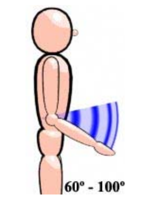
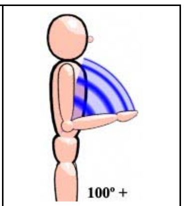
Muscle Use	☐ Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute

Upper arms		
Position	Score	Change score: +1 if arm is abducted or rotated +1 if shoulder is raised -1 if leaning, supporting weight of arm or if posture is gravity assisted
20^0 extension to 20^0 flexion	1	
> 20^0 extension 20^0 – 45^0 flexion	2	
45^0 – 90^0 flexion	3	
> 90^0 flexion	4	

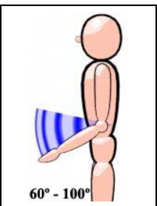
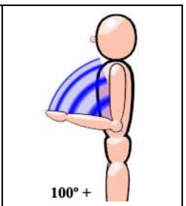
Right Upper Arm					
	☐ Shoulder is raised	☐ Upper arm is abducted or rotated	☐ Leaning or supporting the weight of the arm		
Muscle Use	☐ Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute				

Left Upper Arm					
	☐ Shoulder is raised	☐ Upper arm is abducted or rotated	☐ Leaning or supporting the weight of the arm		
Muscle Use	☐ Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute				

Lower arms	
Movement	Score
$60^0 - 100^0$ flexion	1
$< 60^0$ flexion or $> 100^0$ flexion	2

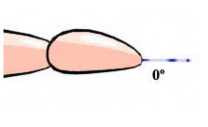
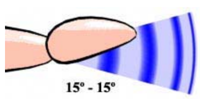
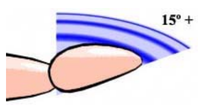
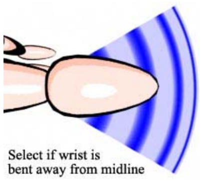
Right Lower Arm			
			

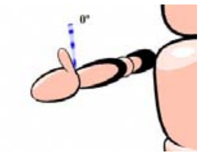
Muscle Use	☐ Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute

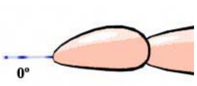
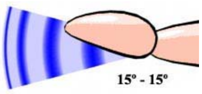
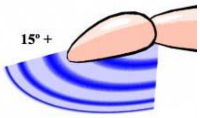
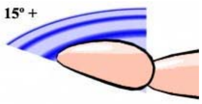
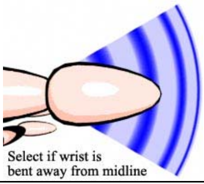
Left Lower Arm			
			

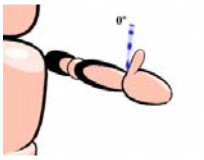
Muscle Use	☐ Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute

Wrists		
Movement	Score	Change score: +1 if wrist is twisted or deviated
$0^0 - 15^0$ flexion/ extension	1	
$> 15^0$ flexion/ extension	2	

Right Wrist				
Deviation		Wrist is bent away from midline		

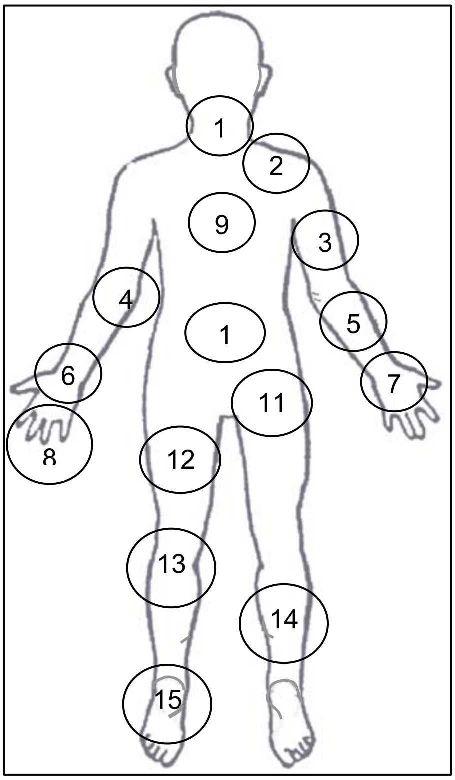
Right Wrist Twist			Force & Load for the Right hand side	SELECT ONLY ONE OF THESE: ☐ less than 5kg load or force ☐ 5–10kg load or force ☐ >10kg load or force ☐ Shock or forces with rapid build-up
Muscle Use	☐ Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute			

Left Wrist				
Deviation		Wrist is bent away from midline		

Left Wrist Twist			Force & Load for the Right hand side	SELECT ONLY ONE OF THESE: ☐ less than 5kg load or force ☐ 5–10kg load or force ☐ >10kg load or force ☐ Shock or forces with rapid build-up
Muscle Use	☐ Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute			

Diagrams adapted from: Osmond Ergonomic workplace solutions. (2007). RULA: Rapid entire body assessment. Available at: http://www.rula.co.uk/ [Accessed: 12th August 2007]

Appendix 3.6: Whole body discomfort scales



Reference No.: W DD/MM/YY/OR/__

Time:

Task:

Recorded at:

Beginning of shift	☐
After one hour	☐

Please circle a number on the scales below to show **how much** discomfort you feel, for each body part

Body part		**No discomfort**						**Extreme discomfort**
1	Neck	0	1	2	3	4	5	6
2	Shoulder (R)	0	1	2	3	4	5	6
	Shoulder (L)	0	1	2	3	4	5	6
3	Upper arm (R)	0	1	2	3	4	5	6
	Upper arm (L)	0	1	2	3	4	5	6
4	Elbow (R)	0	1	2	3	4	5	6
	Elbow (L)	0	1	2	3	4	5	6
5	Forearm (R)	0	1	2	3	4	5	6
	Forearm (L)	0	1	2	3	4	5	6
6	Wrist (R)	0	1	2	3	4	5	6
	Wrist (L)	0	1	2	3	4	5	6
7	Hand (R)	0	1	2	3	4	5	6
	Hand (L)	0	1	2	3	4	5	6
8	Fingers	0	1	2	3	4	5	6
9	Upper/Middle back	0	1	2	3	4	5	6
10	Lower back	0	1	2	3	4	5	6
11	Hips or buttocks	0	1	2	3	4	5	6
12	Upper leg (R)	0	1	2	3	4	5	6
	Upper leg (L)	0	1	2	3	4	5	6
13	Knee (R)	0	1	2	3	4	5	6
	Knee (L)	0	1	2	3	4	5	6
14	Lower leg (R)	0	1	2	3	4	5	6
	Lower leg (L)	0	1	2	3	4	5	6
15	Ankle/Foot (R)	0	1	2	3	4	5	6
	Ankle/Foot (L)	0	1	2	3	4	5	6

Appendix 3.7: Interview proforma (Managers)

User requirements study

This research examines the potential of an established design tool as a means of designing better jobs and equipment for workers in order to minimise musculoskeletal troubles. This interview mainly asks you about your job, access to ergonomics information and MSDs. It takes approximately 30 minutes. There are no right or wrong answers, so please be as honest as possible. All your responses will remain confidential. Any information indicating your identity will be removed and will not be linked to your responses. The information you provide will be valuable for the industrial sector.

Interview: Managers

Reference number	M DD/MM/YYYY/OR/__
Date	DD/MM/YYYY

Investigators

Researcher	**Supervisor**
Himan K.G. Punchihewa	Diane E. Gyi
Email: H.K.G.Punchihewa@lboro.ac.uk	Email: D.E.Gyi@lboro.ac.uk
Tel : 01509 223019	Tel : 01509 223043
Mob : 07956 656761	

Department of Human Sciences, Loughborough University, Loughborough, LE11 3TU

Notes:

Section 1: Job information

1. What is your job title?

2. For how long have you been working in the above capacity?

3. Can you please explain what your job assignments are?

4. For how long have you been working in this sector?

Section 2: Awareness of MSDs

1. Are you concerned about the risk of musculoskeletal problems in your organisation? (☑)

Yes (1) ☐ No (2) ☐

2. Are you thinking about taking action to reduce the risk of musculoskeletal problems in the next 6 months? (☑)

Yes (1) ☐ No (2) ☐

3. Do you have a clear idea of what you are going to do to reduce the risk of musculoskeletal problems in your company? (☑)

Yes (1) ☐ No (2) ☐

4. Are you considering taking action to reduce the risk of musculoskeletal problems in the next month or two? (☑)

Yes (1) ☐ No (2) ☐

5. Have any changes already been made? (☑)

Yes (1) ☐ No (2) ☐

If **yes**, please answer questions 6, 7 and 8.

6. Can you please describe what steps have been taken?

7. How long ago were these changes implemented?

8. If **more than 6 months ago**, is any further attention to the problem planned? (☑)

Yes (1) ☐ No (2) ☐

If "**yes**", please describe.

Section 3: Involvement in the task design decision

1. The company has to design new tasks; order new equipment from time to time. Do you take part in the specification of jobs and equipment in any way? (☑)

Yes (1) ☐ No (2) ☐

If **no**, answer questions 9, 10 and 11. If **yes**, answer all the rest of the questions.

2. What exactly is your involvement in the job and/or equipment specification or ordering process?

3. Rate on the 1-9 scale, **your impact** on the overall decision according to your understanding. (☑)

No impact at all → Very high impact

1	2	3	4	5	6	7	8	9
☐	☐	☐	☐	☐	☐	☐	☐	☐

4. What is the procedure that you normally follow in selecting equipment that your organisation need?

5. Are you aware that there are ergonomics guidelines and standards available to help protect workers from musculoskeletal troubles? (☑)

Yes (1) ☐ No (2) ☐

If **no** continue at question 9. If **yes**, answer questions 6, 7 and 8 too.

6. Are there any ergonomic guidelines and standards are available to you? If so, what are they?

7. How do you use these guidelines and standards in job and/or equipment specification?

8. From where do you have access to ergonomic guidelines and standards?

9. According to your knowledge, who gets involved in obtaining specifications for jobs and/or equipment for your organisation? Name the people who get involved including consultants if any.

10. Does your organisation involve shop floor level workers in the job and/or equipment specification process to derive specifications for new jobs and equipment? (☑)

Yes (1) ☐ No (2) ☐

11. Can you please give reasons for the answer you provided for the previous question?

Thank you so much for participating in this study and hope you would help in the future too.

Appendix 4.1: Tool developed to prioritise risks and user requirements

Constant comparative method described in grounded theory is based on comparing themes identified from narratives from one participant with that of preceding participants (Glaser 1965; Glaser and Strauss, 1967; Lincoln and Guba, 1985; Erlandson, et al., 1993; Boeije, 2002; Teddlie and Tashakkori, 2009) to establish themes common to participants. The frequency of occurrence of a theme could be used to reveal its significance. Therefore, when a number of workers are interviewed, themes identified from narratives of different workers can be compared with each other to obtain frequencies of occurrence of the themes.

The Microsoft® Excel template that was developed partially automated the process of constant comparison. Columns were allocated for different workers and cells under each column were allocated for themes (risks or user requirements) emerged from narratives of the interviews with different workers. It was developed such that the frequency gets updated automatically when a theme is added. It uses the ‘IF’ and ‘SUM’ functions of Microsoft® Excel to add 1 to the ‘Frequency’ (i.e. sum of the number of themes along rows) every time a theme is entered. When using the Microsoft® Excel template, the practitioners are expected to compare the themes and place similar themes along a unique row according to each respondent. Finally, the themes need to be sorted with respect to the frequency in order to obtain the prioritised list of risks and user requirements. The template was developed to accommodate 25 different themes and 20 participants. This process is illustrated using a pseudo scenario with 5 participants as shown in Table A1.

Table A1. The constant comparison process

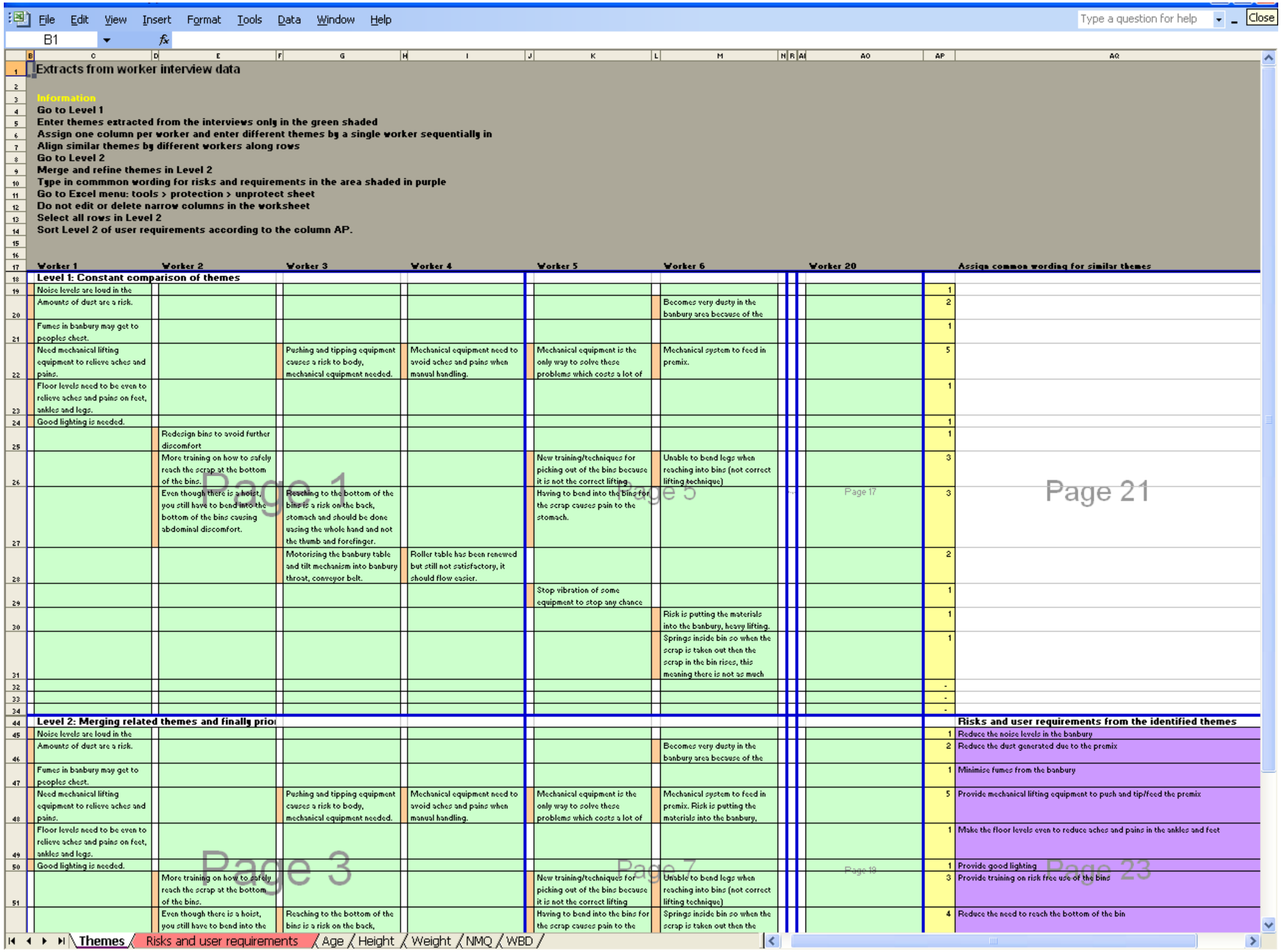
Participant p	Participant q	Participant r	Participant s	Participant t	Frequency
Theme 1	Theme 1		Theme 1	Theme 1	4
Theme 2		Theme 2			2
Theme 3	Theme 3			Theme 3	3
	Theme 4	Theme 4	Theme 4		3
			Theme 5		1

In this scenario, three themes have been extracted from the narrative of ‘Participant p’ (Themes 1, 2 and 3). A new theme (Theme 4) has emerged from the narrative of ‘Participant q’ along with Theme 1 and 3. Although no new themes have emerged from ‘Participant r’, two themes that emerged previously (Theme 2 and 4) have also been identified by ‘participant r’. A new theme (Theme 5) has emerged from ‘Participant s’ in addition to two themes (Theme 1 and 4) which were also identified by earlier participants. No new themes have emerged from ‘Participant t’. However, Theme 1 and 3 have also emerged from the narratives of ‘Participant t’.

When the themes are compared across the range of participants (Frequencies), it could be observed that out of the 5 participants, 4 have expressed Theme 1; 2 have expressed Theme 2; 3 have expressed Theme 3; 3 have expressed Theme 4; and only 1 has expressed Theme 5. Finally, these are prioritised with respect to the percentage of participants expressing a particular requirement (Table A2). This process was practically implemented in the user requirements study (Chapter 3) to prioritise the user identified risks and user requirements.

Table A2. Prioritised risks and user requirements

Themes	Risk or user requirement	No. of participants (out of n = 5)	Percentage of participants
Theme 1	Risk or user requirement 1	4	80
Theme 3	Risk or user requirement 3	3	60
Theme 4	Risk or user requirement 4	3	60
Theme 2	Risk or user requirement 2	2	40
Theme 5	Risk or user requirement 5	1	20


File Edit View Insert Format Tools Data Window Help
Type a question for help
Close
B1
Extracts from worker interview data
Information
Go to Level 1
Enter themes extracted from the interviews only in the green shaded
Assign one column per worker and enter different themes by a single worker sequentially in
Align similar themes by different workers along rows
Go to Level 2
Merge and refine themes in Level 2
Type in commmon wording for risks and requirements in the area shaded in purple
Go to Excel menu: tools > protection > unprotect sheet
Do not edit or delete narrow columns in the worksheet
Select all rows in Level 2
Sort Level 2 of user requirements according to the column AP.
Worker 1
Worker 2
Worker 3
Worker 4
Worker 5
Worker 6
Worker 20
Assign common wording for similar themes
Level 1: Constant comparison of themes
Noise levels are loud in the
Amounts of dust are a risk.
Becomes very dusty in the banbury area because of the
Fumes in banbury may get to peoples chest.
Need mechanical lifting equipment to relieve aches and pains.
Pushing and tipping equipment causes a risk to body, mechanical equipment needed.
Mechanical equipment need to avoid aches and pains when manual handling.
Mechanical equipment is the only way to solve these problems which costs a lot of
Mechanical system to feed in premix.
Floor levels need to be even to relieve aches and pains on feet, ankles and legs.
Good lighting is needed.
Redesign bins to avoid further discomfort
More training on how to safely reach the scrap at the bottom of the bins.
New training/techniques for picking out of the bins because it is not the correct lifting
Unable to bend legs when reaching into bins (not correct lifting technique)
Even though there is a hoist, you still have to bend into the bottom of the bins causing abdominal discomfort.
Reaching to the bottom of the bins is a risk on the back, stomach and should be done using the whole hand and not the thumb and forefinger.
Having to bend into the bins for the scrap causes pain to the stomach.
Motorising the banbury table and tilt mechanism into banbury throat, conveyor belt.
Roller table has been renewed but still not satisfactory, it should flow easier.
Stop vibration of some equipment to stop any chance
Risk is putting the materials into the banbury, heavy lifting.
Springs inside bin so when the scrap is taken out then the scrap in the bin rises, this meaning there is not as much
Level 2: Merging related themes and finally prio
Risks and user requirements from the identified themes
Reduce the noise levels in the banbury
Reduce the dust generated due to the premix
Minimise fumes from the banbury
Mechanical system to feed in premix. Risk is putting the materials into the banbury,
Provide mechanical lifting equipment to push and tip/feed the premix
Make the floor levels even to reduce aches and pains in the ankles and feet
Provide good lighting
Provide training on risk free use of the bins
Reduce the need to reach the bottom of the bin
Themes
Risks and user requirements
Age
Height
Weight
NMQ
WBD

Appendix 4.2: TRIZ-based design principles

Design principle		TRIZ principle	Description
Frequently used design principles			
1	Divide or split up into elements	Segmentation, fragmentation, separation, extraction, removal, taking out	Divide into independent elements; make easy to join and dismantle; promote fragmentation or segmentation; separate interfering features, single out the only necessary feature.
2	Reduce weight or balance weight	Porous materials, composite materials, weight compensation, counterweight, equi-potentiality, same level	Make elements porous or add porous elements (inserts, coatings, etc.); if elements are already porous, and use this to introduce a useful substance or function; change from uniform to composite (multiple) materials; merge with elements that provide lift; interact with the environment (e.g. use buoyancy, magnetic forces); in a potential field, limit position changes.
3	Use rounded shapes and circular motion	Symmetry change, asymmetry, curvature increase, spheroidality	Change the shape from symmetrical to asymmetrical; if a feature is asymmetrical, increase its degree of asymmetry; instead of using rectilinear parts, surfaces, or forms, use curvilinear ones; change from parallelepiped shapes to circular-shaped features; go from straight to circular motion; use centrifugal forces.
4	Use unutilised space, change the orientation	Dimensionality change, another dimension	Move elements in all directions; use a multi-story or under-ground arrangement; tilt or re-orient, lay on the side; use 'another side' of a given area.
5	Fit one inside another	Nesting, nested structures	Place one element inside another; make one element pass through a cavity in another to make good use of available space.
6	Combine elements to make one unit	Merging, joining, combining, integrating	Bring closer together (or merge) identical or similar features, assemble identical or similar elements together; make processes happen at the same time.

Design principle		TRIZ principle	Description
7	Make elements versatile	Local quality, multi-functionality, universality	Make each element function in conditions most suitable for its operation; change structures from uniform to non-uniform; make each element fulfil a different and useful function; make elements perform multiple functions; minimise the need for new elements.
8	Increase adaptability to suit the conditions	Dynamic parts, dynamism, increasing flexibility	Allow equipment, processes and the external environment to change to operate optimally; divide into features capable of movement relative to each other; if fixed or inflexible, make movable or adaptive.
9	Use flexible and hollow structures rather than solid structures	Flexible shells & thin films	Use flexible shells and thin films instead of three dimensional structures; isolate from the external environment using flexible shells and thin films.
10	Take counter measures for anticipated issues	Preliminary counteraction, preliminary action, beforehand compensation, intermediary action, partial or excessive action	Replace harmful effects with anti-actions; create pre-stresses to oppose known undesirable working stresses; masking before harmful exposure; perform the required change either fully or partially before it is needed; pre-arrange for convenience and to save time; prepare emergency means to compensate for low reliability; use intermediary processes; merge one element temporarily with another; if 100% is hard to achieve, use the same method repeatedly to make it easier to solve.
11	Skip or quickly perform the risky tasks	Hurrying, rushing through, skipping	Conduct a process, or certain stages of a process (e.g. destructible, harmful or hazardous operations) at high speed.
12	Use cyclic/pulsating action or ensure continuous action	Periodic action, mechanical vibration, continuity of action	Instead of continuous action, use periodic or pulsating actions; if an action is already periodic, change the periodic magnitude or frequency; use pauses between impulses to perform a different action; use oscillation/ vibration; increase frequency; use an object's resonant frequency; use piezoelectric vibrators instead of mechanical ones; use combined ultrasonic and electromagnetic field oscillations; carry on work continuously; make all elements work at full load, all the time; eliminate all idle or intermittent actions or work.

Design principle		TRIZ principle	Description
13	Check reversing the order of operation	Other way around, do it in reverse	Invert the processes; make movable parts (or the external environment) fixed and fixed parts movable; turn the elements 'upside down'.
14	Make use of harmful effects	Blessing in disguise, convert harm to benefit	Use harmful factors to achieve a positive effect; eliminate the primary harmful action by adding it to another harmful action; amplify harmful factors so that they are no longer harmful.
15	Use feedback signals	Feedback	Introduce feedback (referring back, cross-checking) to improve functions; if feedback is already used, change its magnitude or influence.
16	Make use of idling resources	Self-service	Make an object serve itself by performing auxiliary helpful functions; regenerate/repair by itself; use waste resources, energy, or substances.
17	Use the properties of gas and liquid	Pneumatics and hydraulics	Use gas and liquid parts of instead of solid parts (e.g. inflatable, filled with liquids, air cushion); use buoyancy; use negative pressure; use foam as a combination of gas and liquid.
18	Remove or restore used substances	Discard & recover	Make portions of elements that have fulfilled their functions go away (discard by dissolving, evaporating, etc.) or change properties during operation; Conversely, restore consumable elements during operation.
19	Replace mechanical actions with other physical actions	Mechanical interaction substitution	Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means; use electric, magnetic and electromagnetic fields to interact with the object; change from static to movable fields, from unstructured fields to those having structure; use fields in conjunction with field-activated (e.g. ferromagnetic) particles.
20	Use cheap disposable copies	Copying, cheap disposables	Instead of an unavailable, expensive, fragile elements, use simpler and cheap copies; replace an elements with optical copies; if visible optical copies are already used, move to infrared or ultraviolet copies; replace an expensive element with a multiple of cheap elements comprising certain qualities (such as service life, for instance).

Design principle		TRIZ principle	Description
Occasionally used design principles			
21	Make use of physical property changes	Optical property changes, colour change, parameter change, property change, phase transitions	Change the colour of an element or its external environment; change the transparency of an element or its external environment; use coloured additives; change an object's physical state (e.g. to a gas, liquid, or solid.); change the concentration or consistency; change the temperature; change method; use phenomena occurring during phase transitions (e.g. volume changes, loss or absorption of heat, etc.).
22	Make identical material interact	Homogeneity	Make elements interact with a given element of the same material (or material with identical properties).
23	Use expansion and contraction due to temperature change	Thermal expansion	Use thermal expansion (or contraction) of materials; if thermal expansion is being used, use multiple materials with different coefficients of thermal expansion.
24	Use oxygen to help burning/oxidising	Strong oxidants	Replace common air with oxygen-enriched air; replace enriched air with pure oxygen; expose air or oxygen to ionizing radiation; use ionized oxygen; replace ozonised (or ionized) oxygen with ozone.
25	Use inert gases to prevent burning/oxidising	Inert atmosphere	Replace a normal environment with an inert one; add neutral elements or inert additives to elements.

Appendix 5.1: Email sent to practitioners

SUB: Are you a practitioner of ergonomics and/or design?

Are you a practitioner of ergonomics and/or design? Are you interested in participatory design? Do you have expertise in MSD risk assessment, product evaluation or design?

Research is being conducted at Loughborough University to develop a participatory design tool to help design better equipment and processes for workers in order to reduce work-related MSDs.

Initially, we are looking for people to complete a short questionnaire (15 minutes) available through the link below. We are also looking for people to try out the tool.

http://www.surveymonkey.com/s.aspx?sm=LCN_2bOJ9gPrnC5BB5bqozPQ_3d_3d

We would be grateful if you could forward this email to other colleagues and practitioners in your organisation who might be interested.

Please contact Himan Punchihewa (h.k.g.punchihewa@lboro.ac.uk) or Diane Gyi (d.e.gyi@lboro.ac.uk) if you require further information.

Thanking you for your help.

Regards,

Himan Punchihewa

Appendix 5.2: Notice published in 'The Ergonomist'

Search for practitioners of ergonomics and design

Are you a practitioner of ergonomics and/or design? Are you interested in participatory design? Do you have expertise in MSD risk assessment, product evaluation or design?

Research is being conducted at Loughborough University to develop a participatory design tool to help design better equipment and processes for workers in order to reduce work-related MSDs. Initially, we are looking for people to complete a short questionnaire. We are also looking for people to try out the tool. Please email Himan Punchihewa (h.k.g.punchihewa@lboro.ac.uk) or Diane Gyi (d.e.gyi@lboro.ac.uk) for more information.

The survey questionnaire can be found at http://tinyurl.com/a98ftp

The Ergonomist: Newsletter of the Ergonomics Society. No. 463 January 2009.

Appendix 5.3: Questionnaire (Practitioner survey)

Practitioner survey

We are conducting research to examine the potential of a tool for participatory design to enable the development of equipment and processes for workers to reduce work-related musculoskeletal disorders (MSDs).

We are interested in your views as an expert, on the available methods for participatory design and what you expect from such methods.

This questionnaire will take 5-10 minutes of your time to complete. There are no right or wrong answers. All responses will be confidential. Any information indicating your identity will be removed and will not be linked to your responses. The information you provide is valuable to refine the tool being developed. Please answer the questions as fully as possible.

Finally, please indicate whether you would like to participate in a short interview and get the chance to try the tool. Please complete the questionnaire by **20th August 2009**.

Investigators

Researcher

Himan K.G. Punchihewa

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Supervisor

Diane E. Gyi

Email: D.E.Gyi@lboro.ac.uk

Tel : 01509 223043

Fax : 01509 223940

Reference Number P DD/MMM/YYYY/OR/__

Date / / (DD/MM/YYYY)

Department of Human Sciences, Loughborough University, Loughborough, Leics. LE11 3TU

Section 1: Personal and job information

1. Gender.

☐ Male ☐ Female

2. Your **company name**.

3. What is your **current occupation**?

☐ Ergonomist ☐ Engineer ☐ Human factors engineer
☐ Consultant ☐ Manager ☐ Health and safety practitioner
☐ Lecturer ☐ Designer
☐ Other (please specify)

4. What are your **job responsibilities** (select **all** that apply)?

☐ MSD risk assessment ☐ Equipment and task design
☐ User measurements assessment ☐ Conducting user trials
☐ User needs analysis ☐ Managing ergonomics projects
☐ Other (please specify)

5. Years **experience** as a practitioner?

☐ 0-5 years ☐ 6-10 years ☐ 11-20 years ☐ 21 plus years

6. What is your **expertise** as a practitioner (select **all** that apply)?

☐ Anthropometry/ biomechanics ☐ Job/ task analysis
☐ Evaluation of MSD risk ☐ Management of work-related MSDs
☐ Systems analysis and design ☐ Evaluation of products/ systems
☐ Product/system development ☐ Product/system design and testing
☐ User requirements analysis and specification ☐ Participatory ergonomics
☐ Other (please specify)

Section 2: Participatory methods to help reduce work-related MSDs

1. What methods do you use to **assess the risks** for developing work-related MSDs? (select **all** that apply)

☐ RULA ☐ REBA ☐ Body discomfort scale
☐ QEC ☐ OWAS ☐ PATH
☐ Other (please specify)

2. What methods do you use to **identify** user requirements to reduce work-related MSDs? (select **all** that apply)

☐ Questionnaires ☐ User-interviews ☐ Focus groups
☐ Observation techniques ☐ Checklists ☐ Experience-based judgements
☐ Other (please specify)

3. Do you use any formal method(s)/tool(s) to help **prioritise** the user requirements that you identify in order to reduce work-related MSDs?

☐ Yes ☐ No

If **yes**, please state the method(s)/tool(s).

4. What method(s)/tool(s) do you use to help **develop specific design solutions** to reduce work-related MSDs? (select **all** that apply)

☐ Ergonomics guidelines ☐ Study similar cases ☐ Experience-based judgements
☐ Innovation
☐ Other (please explain)

5. If you selected **innovation** in question 4, please state/explain the method(s)/tool(s)

6. Do you follow any formal or informal **participatory process(es)** to help design to reduce workplace risks for developing work-related MSDs?

☐ Yes ☐ No

If **yes**, please state the process(es).

7. With particular reference to reducing work-related MSDs, how would you evaluate the **performance** of the method(s)/tool(s) that you use with regard to the following elements? Rate using the given 7-point (1-7) scale.

	Participatory elements	**Very poor** →						**Excellent**
		1	2	3	4	5	6	7
1	Indentifying MSD risks	☐	☐	☐	☐	☐	☐	☐
2	Obtaining user requirements	☐	☐	☐	☐	☐	☐	☐
3	Prioritising these requirements	☐	☐	☐	☐	☐	☐	☐
4	Identifying design solutions to address these requirements	☐	☐	☐	☐	☐	☐	☐
5	Ability to present user requirements/design solutions	☐	☐	☐	☐	☐	☐	☐
6	Checking the feasibility of any solutions	☐	☐	☐	☐	☐	☐	☐
7	Integration of the above elements	☐	☐	☐	☐	☐	☐	☐
8	The ability to record knowledge for improvements/future applications	☐	☐	☐	☐	☐	☐	☐

Section 3: Participatory design tool to help reduce work-related MSDs

1. How important is an **integrated tool** to help the process involved in designing/ improving equipment and reducing work-related MSDs? Rate using the given 7-point (1-7) scale.

Not important →						Highly important
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

Please **explain** your answer.

2. As a practitioner, please rate the **importance** of the following elements for a new participatory design tool. Rate using the given 7-point (1-7) scale.

	Participatory elements	**Not important** →						**Highly important**
		1	2	3	4	5	6	7
1	Indentifying MSD risks	☐	☐	☐	☐	☐	☐	☐
2	Obtaining user requirements	☐	☐	☐	☐	☐	☐	☐
3	Prioritising these requirements	☐	☐	☐	☐	☐	☐	☐
4	Identifying design solutions to address these requirements	☐	☐	☐	☐	☐	☐	☐
5	Ability to present user requirements/design solutions	☐	☐	☐	☐	☐	☐	☐
6	Checking the feasibility of any solutions	☐	☐	☐	☐	☐	☐	☐
7	Integration of the above elements	☐	☐	☐	☐	☐	☐	☐
8	The ability to record knowledge for improvements/future applications	☐	☐	☐	☐	☐	☐	☐

3. According to your experience, what **additional elements** do you think are required to make this design tool more comprehensive?

Section 4: Further research

1. Would you be able to participate in a **short interview** to get the chance to try (and receive a copy of) the design tool which is being developed?

☐ Yes ☐ No

2. Would you like to receive a copy of the participatory design tool **when it is developed in 2010**?

☐ Yes ☐ No

3. Would you like to receive a **summary of findings** of this questionnaire?

☐ Yes ☐ No

If you ticked **yes** in any of the above questions, please provide your:

Name

Email address

Contact telephone number

Any other comments.

Thank you so much for completing this questionnaire.

Appendix 6.1: Participant information sheet (Practitioner interview study)

Thank you very much for agreeing to participate in this unique study. It is carried out as postgraduate research in the Department of Human Sciences, Loughborough University. The aim of this research is to develop a design approach (and guidance tool) for practitioners to help design equipment, facilities, procedures and training to reduce work-related MSDs. It is hoped that this approach will benefit the industry at large.

People do various tasks regularly at work. However, some work tasks give rise to MSDs. This may be attributed to unsuitable equipment, facilities, procedures and training available to workers (users). Literature suggests lack of collaboration among the stakeholders of the design process as one of the reasons for unsuitable designs. In this pursuit, we have developed a design approach for practitioners to help design and enhance collaboration among stakeholders in the design process.

You may well know the methods already available to you, and what you need to help design. We need your expertise in evaluating this design approach. The design approach will first be demonstrated and then you will be interviewed. The interview will take about 45 minutes to 1 hour of your time. The information that you provide is invaluable for this research. Further, your information will be treated in strict confidence.

Please feel free to contact us at any time if you have any questions (contact details are given below). I look forward to working with you.

Himan K.G. Punchihewa

Contact information

Researcher

Mr. Himan K.G. Punchihewa

Email: H.K.G.Punchihewa@lboro.ac.uk
Tel : 01509 223019
Mob : 07956 656761

Supervisor

Dr. Diane E. Gyi

Email: D.E.Gyi@lboro.ac.uk
Tel : 01509 223043

Department of Human Sciences (Ergonomics), Loughborough University, LE11 3TU

Loughborough University

Appendix 6.2: Interview guide (Practitioner interview study)

Practitioner interview study

This research examines the potential of a Quality Function Deployment (QFD) based design approach as a means of designing better equipment, facilities, procedures and training for workers in order to help reduce work-related musculoskeletal troubles. Initially, the design approach will be demonstrated to you. After that, you will be interviewed to review the guidance tools to facilitate this approach. It will approximately take 45 minutes – 1 hour. There are no right or wrong answers, so please be as honest as possible. All responses will remain confidential. Any information indicating your identity will be removed and will not be linked to your responses. The information you provide will be valuable for the future development of this approach.

Interview: Practitioners

Reference number	P DD/MM/YY/OR/__
Date	DD/MM/YYYY

Investigators

Researcher	Supervisor
Himan K.G. Punchihewa	Diane E. Gyi
Email: H.K.G.Punchihewa@lboro.ac.uk	Email: D.E.Gyi@lboro.ac.uk
Tel : 01509 223019	Tel : 01509 223043
Mob : 07956 656761	

Department of Human Sciences, Loughborough University, Loughborough, LE11 3TU

Notes:

Section 1: Identifying risks and obtaining user requirements

1. In your opinion, what are the positive aspects of this approach to **identify risks and obtain user requirements** to help reduce work-related MSDs? (e.g. use of existing methods and ability to bring in user experience etc.)

2. In your opinion, what are the limitations of this approach to **identify risks and obtain user requirements** to help reduce work-related MSDs? (e.g. expert knowledge required, and time and effort to learn the approach etc.)

3. Do you think this approach will appeal to practitioners generally? (☑)

Yes (1) ☐ No (2) ☐

Please give reasons.

4. Do you think this approach will work in the field environment? (☑)

Yes (1) ☐ No (2) ☐

Please give reasons.

5. What aspects of the approach do you think have to be altered/ modified?

Section 2: Prioritising the risks and user requirements

1. In your opinion, what are the positive aspects of this approach to **prioritise the risks and user requirements** to help reduce work-related MSDs (e.g. easy way of obtaining a priority list from user expressions)?

2. In your opinion, what are the limitations of this approach to **prioritise the risks and user requirements** to help reduce work-related MSDs (e.g. having to learn prioritisation techniques and not being able to recon whether the priority order is correct etc.?

3. Do you think this prioritisation approach will appeal to practitioners generally? (☑)

Yes (1) ☐ No (2) ☐

Please give reasons.

4. Do you think this prioritisation approach will work in the field environment? (☑)

Yes (1) ☐ No (2) ☐

Please give reasons.

5. What aspects of this approach do you think have to be altered/ modified?

Section 3: Identifying design solutions and selecting acceptable solutions

1. In your opinion, what are the positive aspects of this approach to **identify feasible design solutions** for the risks and user requirements to help reduce work-related MSDs (e.g. providing systematic guidance, aid for brainstorming etc.)?

2. In your opinion, what are the limitations of this approach to **identify feasible design solutions** for the risks and user requirements to help reduce work-related MSDs (e.g. limiting the thinking process, may miss possible solutions etc.)?

3. Do you think this design approach will appeal to practitioners generally? (☑)

Yes (1) ☐ No (2) ☐

Please give reasons.

4. Do you think this design approach will work in the field environment? (☑)

Yes (1) ☐ No (2) ☐

Please give reasons.

5. What aspects of this design approach do you think have to be altered/ modified?

Section 4: Presentation of risks and user requirements, and solutions

1. In your opinion, what are the positive aspects of the design approach to **present the risks and user requirements, and design solutions** (e.g. ability to show an overall picture etc.)?

2. In your opinion, what are the limitations of the design approach to **present the risks and user requirements, and design solutions** (e.g. can be complicated, too much information, time consumption etc.)?

3. Do you think this presentation approach will appeal to practitioners in general? (☑)

Yes (1) ☐ No (2) ☐

Please give reasons.

4. Do you think this presentation approach will work in the field environment? (☑)

Yes (1) ☐ No (2) ☐

Please give reasons.

5. What aspects of this presentation approach do you think have to be altered/ modified?

Section 5: Recording knowledge for future applications

1. In your opinion, what are the positive aspects of this database approach to **record knowledge** for future applications (e.g. quick and easy reference of solutions, cheap way of developing one's own solutions etc.)?

2. In your opinion, what are the limitations of this database approach to **record knowledge** for future applications (e.g. inability to record in words because the solutions are complicated, under what criteria are the solutions are categorised etc.)?

3. Do you think this database approach will appeal to practitioners generally? (☑)

Yes (1) ☐ No (2) ☐

Please give reasons.

4. Do you think this database approach will work in the field environment? (☑)

Yes (1) ☐ No (2) ☐

Please give reasons.

5. What aspects of this database approach do you think have to be altered/ modified?

Section 6: Integrating the features

1. What aspects of this approach in general do you think have to be altered/ modified? What needs to be included? What needs to be excluded?

2. Any other comments on the overall approach.

Thank you so much for participating in this study.

Appendix 7.1: Participant information sheet (Practitioner case studies)

Thank you very much for agreeing to participate in this unique study. It is carried out as postgraduate research in the Department of Human Sciences, Loughborough University. The aim of this research is to develop a design approach (and guidance tool) for practitioners to help design equipment, facilities, procedures and training to reduce work-related MSDs. It is hoped that this approach will benefit the industry at large by helping to enhance collaboration among stakeholders in the design process.

At the beginning of the session, you will be briefed about the study, the design approach (and the guidance tool) and will be asked to familiarise with it. You will be asked to use the guidance tool to identify acceptable solutions for any two risks or user requirements from the prioritised list you have already prepared and present the information using the QFD matrix template. You will also be requested to update the database to record knowledge for future use. The task will be continued for one and half hours.

Feel free to ask questions while you are trying out the design approach. During the study, you will be observed and then a post-task short interview will be conducted. In addition, any relevant documents will be requested. The information that you provide is invaluable for this research. Further, information you provide will be treated in strict confidence.

Please feel free to contact us at any time if you have any questions (contact details are given below). I look forward to working with you.

Himan K.G. Punchihewa

Contact information

Researcher

Mr. Himan K.G. Punchihewa

Email: H.K.G.Punchihewa@lboro.ac.uk
Tel : 01509 223019
Mob : 07956 656761

Supervisor

Dr. Diane E. Gyi

Email: D.E.Gyi@lboro.ac.uk
Tel : 01509 223043

Department of Human Sciences (Ergonomics), Loughborough University LE11 £TU

Appendix 7.2: Observations protocol (Practitioner case studies)

Practitioner case study (Observations)

This research examines the potential of a Quality Function Deployment (QFD) based design approach as a means of designing better equipment and processes for workers in order to help reduce work-related musculoskeletal troubles. Initially, the design approach will be demonstrated to you. Then, you will be allowed to use the design approach and the guidance tool in one of your current projects. You are free to ask questions at any time during the study and support will be provided whenever required. During the time you use the design approach, observations will be noted. At the end, you will be interviewed to review the design approach. There are no right or wrong answers, so please be as honest as possible. All information will remain confidential. Any information indicating your identity will be removed and will not be linked to your responses. The information you provide will be valuable for the future development of this design approach. This session will take 2-3 hours of your time.

Case study

Reference number	P DD/MM/YY/OR/__
Date	DD/MM/YYYY

Investigators

Researcher	**Supervisor**
Himan K.G. Punchihewa	Diane E. Gyi
Email: H.K.G.Punchihewa@lboro.ac.uk	Email: D.E.Gyi@lboro.ac.uk
Tel : 01509 223019	Tel : 01509 223043
Mob : 07956 656761	

Department of Human Sciences, Loughborough University, Loughborough, Leics. LE11 3TU

Notes:

Section 1: Identifying acceptable solutions

1. Selected user requirement.

2. Rationale behind selection.

3.a. Time at which the practitioner start to identify acceptable solutions.

3.b. Time completed.

4. Solutions obtained.

Solution	Used design principle	Whether it is for equipment, facilities, procedure or training

5. Questions asked by practitioners.

6. Difficulties encountered by practitioners.

7. Documents used by practitioners.

Section 2: Presentation of risks, requirements and solutions

1.a. Time at which the practitioner start to fill in the QFD matrix.

1.b. Time completed.

2. Questions asked by practitioners.

3. Difficulties encountered by practitioners.

4. Documents used by practitioners.

Section 3: Recording knowledge for future use

1.a. Time at which the practitioner start to fill in information to the database.

1.b. Time Completed.

2. Questions asked by practitioners.

3. Difficulties encountered by practitioners.

4. Documents used by practitioners.

Section 3: Other observations

Appendix 7.3: Interview guide (Practitioner case studies)

Practitioner case study (Interview)

This research examines the potential of a Quality Function Deployment (QFD) based design approach as a means of designing better equipment and processes for workers in order to help reduce work-related musculoskeletal troubles. Initially, the design approach will be demonstrated to you. Then, you will be allowed to use the design approach and the guidance tool in one of your current projects. You are free to ask questions at any time during the study and support will be provided whenever required. During the time you use the design approach, observations will be noted. At the end, you will be interviewed to review the design approach. There are no right or wrong answers, so please be as honest as possible. All information will remain confidential. Any information indicating your identity will be removed and will not be linked to your responses. The information you provide will be valuable for the future development of this design approach. This session will take 2-3 hours of your time.

Case study

Reference number	P DD/MM/YY/OR/__
Date	DD/MM/YYYY

Investigators

Researcher	Supervisor
Himan K.G. Punchihewa	Diane E. Gyi
Email: H.K.G.Punchihewa@lboro.ac.uk	Email: D.E.Gyi@lboro.ac.uk
Tel : 01509 223019	Tel : 01509 223043
Mob : 07956 656761	

Department of Human Sciences, Loughborough University, Loughborough, LE11 3TU

Notes:

Section 1: Identifying risks and obtaining user requirements

1. How were the risks and requirements identified (what methods were used)?

Section 2: Prioritising the risks and user requirements

1. Did you use this tool to prioritise the risk and user requirements?

Yes (1) ☐ No (2) ☐

2. In your opinion, what are the **capabilities** of this approach to prioritise risks and requirements to help reduce work-related MSDs?

3. In your opinion, what are the **limitations** of this approach to prioritise risks and requirements to help reduce work-related MSDs?

4. What are the elements that need to be **added, omitted or modified** (Tasks you would have performed differently) to make this approach more useful to the industry?

5. How would you rate the performance of this approach to help practitioners prioritise risks and user requirements?

Very poor						Excellent
1	2	3	4	5	6	7

Section 3: Identifying acceptable solutions

1. In your opinion, what are the **capabilities** of this approach to identify acceptable solutions to help reduce work-related MSDs?

2. In your opinion, what are the **limitations** of this approach to identify acceptable solutions to help reduce work-related MSDs?

3. What are the elements that need to be **added, omitted or modified** (Tasks you would have performed differently) to make this approach more useful to the industry?

4. How would you rate the performance of this approach to help practitioners identify design solutions to the risks and user requirements?

Very poor			→			Excellent
1	2	3	4	5	6	7

5. How would you rate the performance of this approach to help practitioners select acceptable solutions (i.e. check feasibility)?

Very poor			→			Excellent
1	2	3	4	5	6	7

Section 4: Presentation of risks, requirements and solutions

1. In your opinion, what are the **capabilities** of this approach to present risks, requirements and solutions to help reduce work-related MSDs?

2. In your opinion, what are the **limitations** of this approach to present risks, requirements and solutions to help reduce work-related MSDs?

3. What are the elements that need to be **added, omitted or modified** (Tasks you would have performed differently) to make this approach more useful to the industry?

4. How would you rate the performance of this presentation approach to help practitioners present risks, requirements and solutions?

Very poor			→			Excellent
1	2	3	4	5	6	7

Section 5: Recording knowledge for future use

1. In your opinion, what are the **capabilities** of this approach to help record knowledge for future use?

2. In your opinion, what are the **limitations** of this approach to help record knowledge for future use?

3. What are the elements that need to be **added, omitted or modified** (Tasks you would have performed differently) to make this approach more useful to the industry?

4. How would you rate the performance of this database approach to help practitioners record knowledge for future use?

Very poor → Excellent

1	2	3	4	5	6	7

Section 6: Integrating the elements

1. Overall, how useful would this approach be as an **integrated tool** to help the process involved in designing/ improving equipment and processes to reduce work-related MSDs?

2. What is the way forward to make this approach more **useful** to the industry?

3. Any other comments on the overall approach.

4. How would you rate the performance of the features discussed above in terms of **integration** of the approach?

Very poor → Excellent

1	2	3	4	5	6	7

5. Overall, how useful would this approach be as an integrated tool to help the process involved in designing/ improving equipment and processes to reduce work-related MSDs?

Not useful → Highly useful

1	2	3	4	5	6	7

Thank you so much for participating in this study.

Appendix 7.4: Documents checklist (Practitioner case studies)

Practitioner case study (Document checklist)

This research examines the potential of a Quality Function Deployment (QFD) based design approach as a means of designing better equipment and processes for workers in order to help reduce work-related musculoskeletal troubles. Initially, the design approach will be demonstrated to you. Then, you will be allowed to use the design approach and the guidance tool in one of your current projects. You are free to ask questions at any time during the study and support will be provided whenever required. During the time you use the design approach, observations will be noted. At the end, you will be interviewed to review the design approach. There are no right or wrong answers, so please be as honest as possible. All information will remain confidential. Any information indicating your identity will be removed and will not be linked to your responses. The information you provide will be valuable for the future development of this design approach. This session will take 2-3 hours of your time.

Case study

Reference number	P DD/MM/YY/OR/__
Date	DD/MM/YYYY

Investigators

Researcher	Supervisor
Himan K.G. Punchihewa	Diane E. Gyi
Email: H.K.G.Punchihewa@lboro.ac.uk	Email: D.E.Gyi@lboro.ac.uk
Tel : 01509 223019	Tel : 01509 223043
Mob : 07956 656761	

Department of Human Sciences, Loughborough University, Loughborough, LE11 3TU

Notes:

Section 1: Background information and related documents

1. Description of the studied work task.

Printout ☐ Electronic copy ☐

2. Key task elements of the work task (obtain related documents if possible).

Printout ☐ Electronic copies ☐

Task element	Photographs	Diagrams	Information sheets	Other

3. Classification of the work task

a) cyclic work task-stationary workstation	b) cyclic work task-variable environment
c) variable work task-stationary workstation	d) variable work task-variable environment

4. Number of workers engaged in the work task.

5. Worker exposure time to the work task.

6. Risk assessment data relevant to the work task (e.g. prevalence, REBA, WBD data etc. (obtain if possible)

Printouts ☐ Electronic copies ☐

Criteria	Data and description	Relevant documents

7. Methods used to obtain user requirements. (obtain if possible)

Printouts ☐ Electronic copies ☐

Documents

8. The prioritised risks and requirements

Printout ☐ Electronic copy ☐ Documentary evidence ☐

9. Documents used by practitioners during the session (obtain if possible)

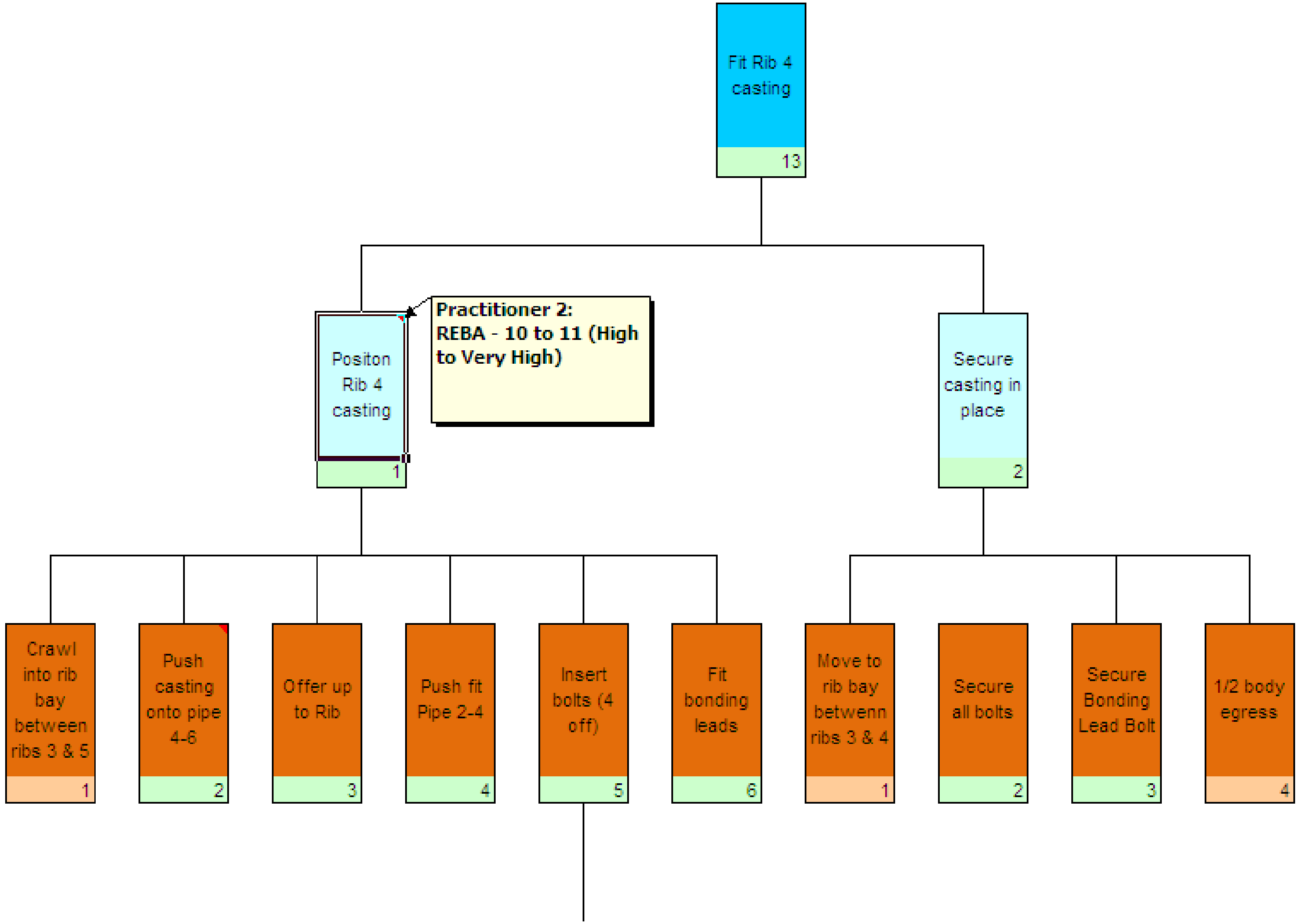
Printouts ☐ Electronic copies ☐

1
2
3
4
5

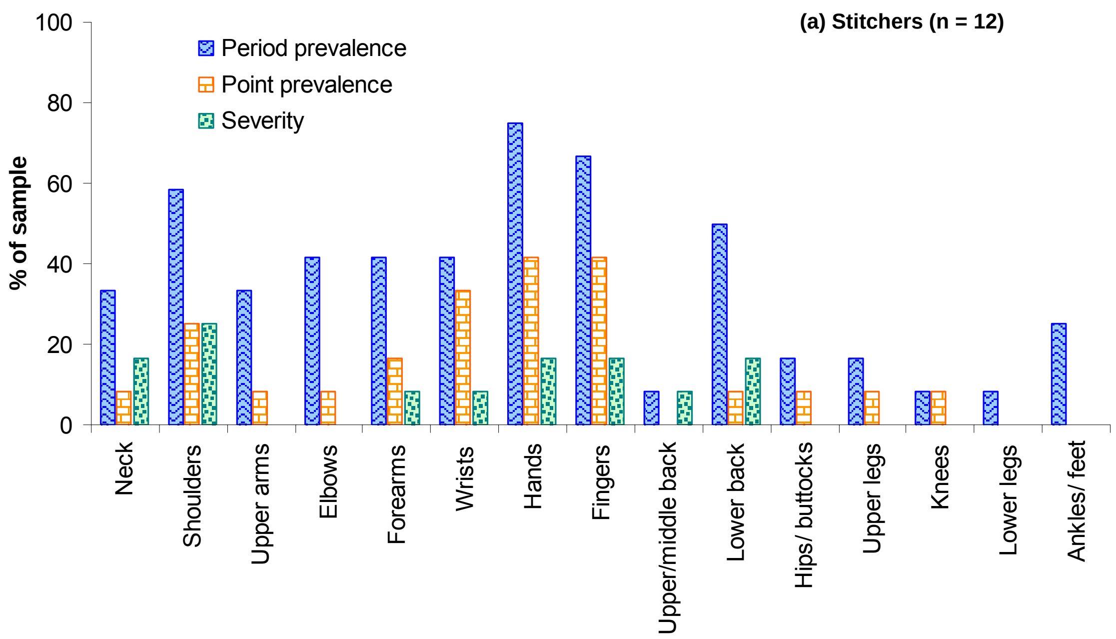
10. Any other relevant documents (obtain if possible)

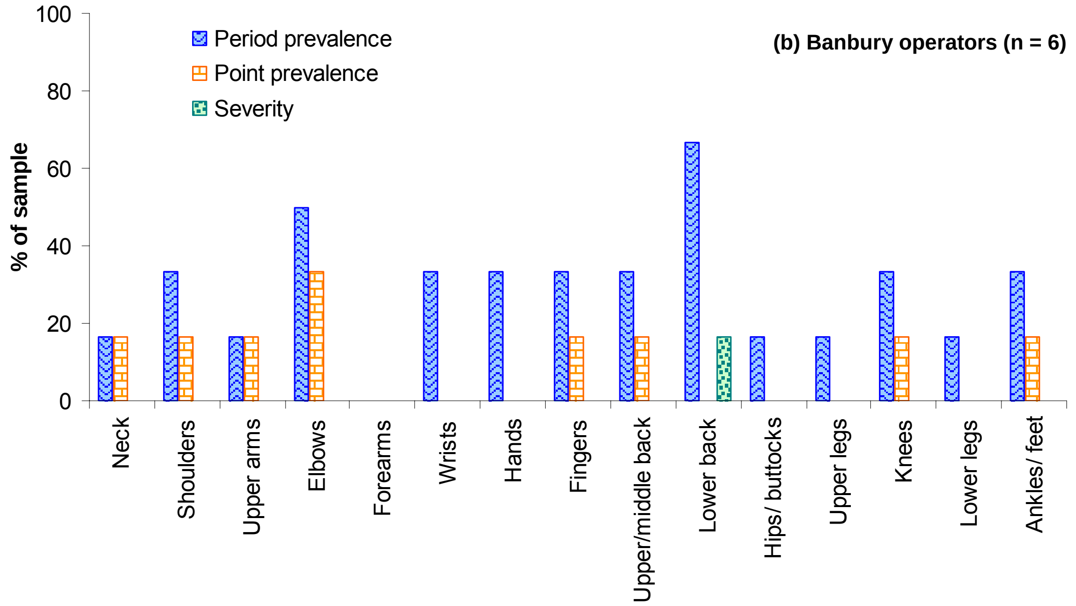
Printouts ☐ Electronic copies ☐

Appendix 7.5: A section of the HTA diagram (Pipe installation study)

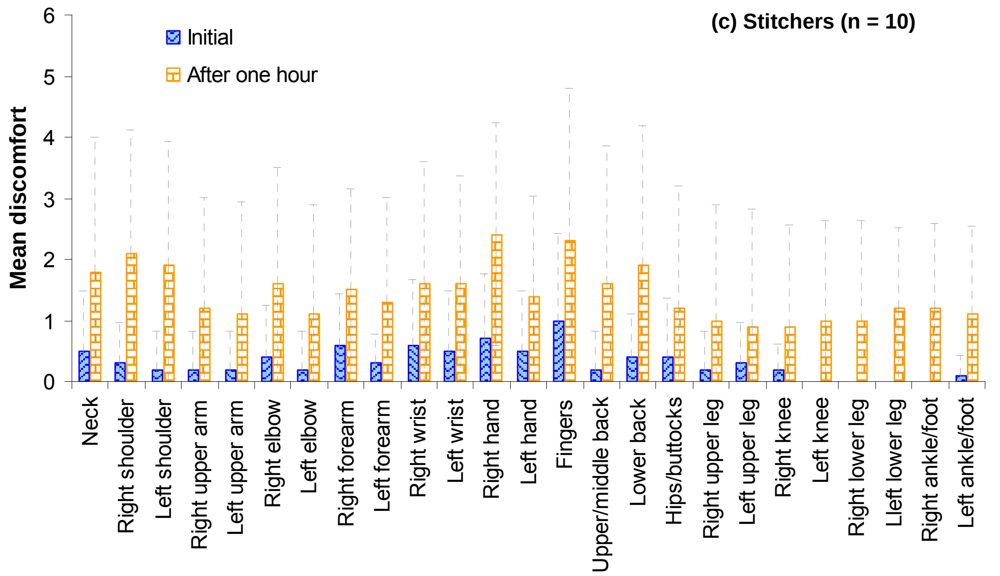


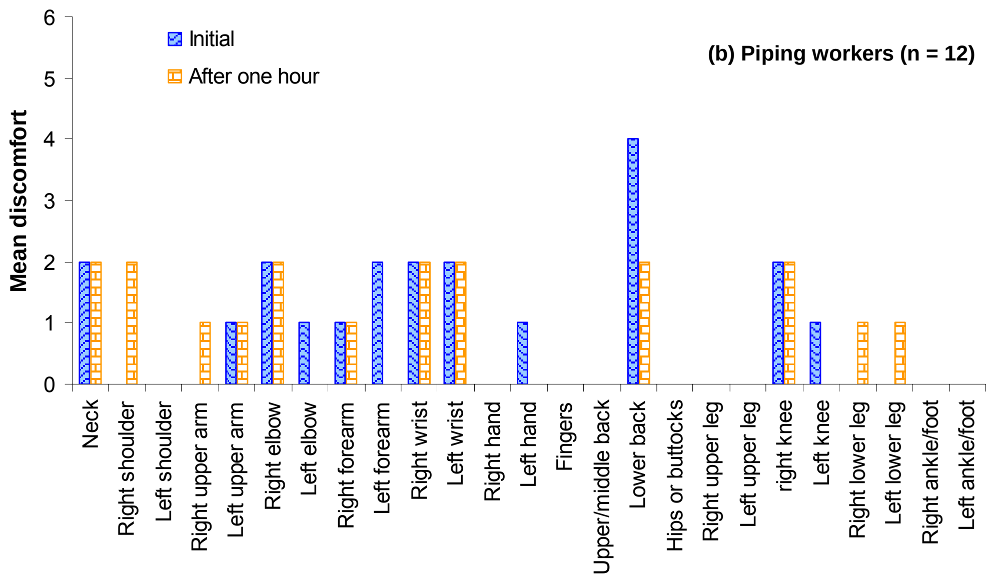
Appendix 7.6: NMQ data (Practitioner case studies)

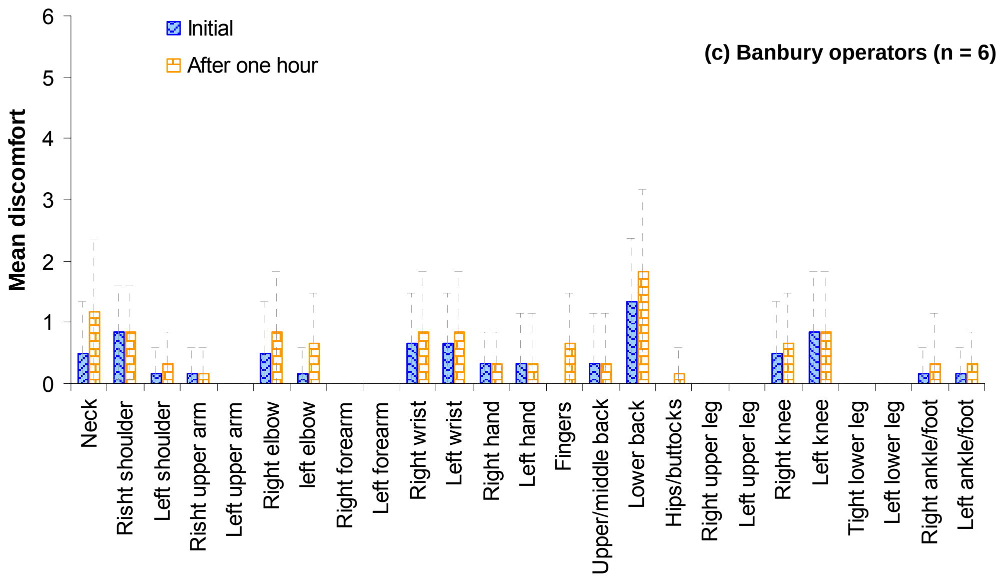




Appendix 7.7: WBD data (Practitioner case studies)



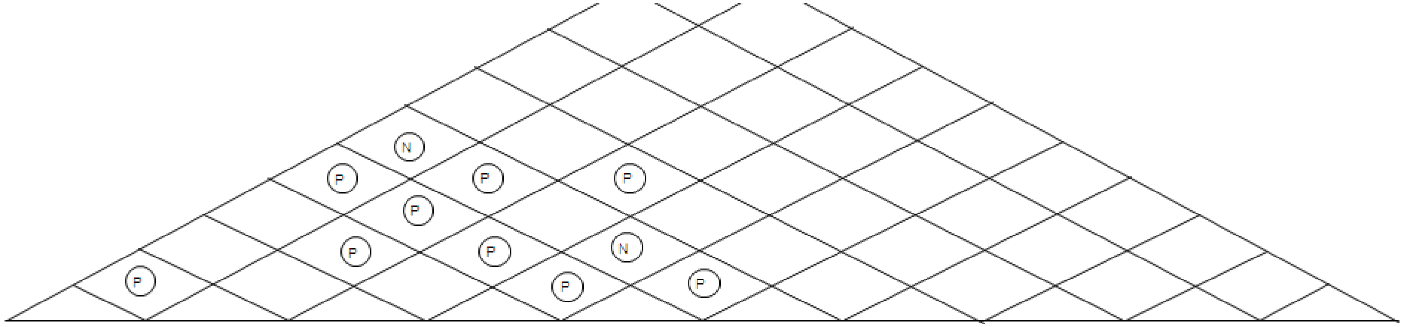




Appendix 7.8: REBA risk levels (Stitching operation study)

Participant	Manoeuvring the trolley	Loading the casing	Extruding hot rubber	Repairing beads and punctures	Rotating the casing	Unloading the casing	Loading to trolleys
Participant 7	Medium [Necessary]	Negligible [None necessary]	Low [May be necessary]	High [Necessary soon]	High [Necessary soon]	Medium [Necessary]	High [Necessary soon]
Participant 8	Not recorded	Medium [Necessary]	High [Necessary soon]	Very high [Necessary now]	Medium [Necessary]	Medium [Necessary]	Medium [Necessary]
Participant 10	Not recorded	Negligible [None necessary]	Medium [Necessary]	Very high [Necessary now]	High [Necessary soon]	Medium [Necessary]	Medium [Necessary]
Participant 11	Not recorded	Low [May be necessary]	Medium [Necessary]	Very high [Necessary now]	High [Necessary soon]	Medium [Necessary]	Medium [Necessary]
Participant 13	Not recorded	Medium [Necessary]	Low [May be necessary]	High [Necessary soon]	Very high [Necessary now]	Medium [Necessary]	High [Necessary soon]
Participant 14	Not recorded	Negligible [None necessary]	Low [May be necessary]	High [Necessary soon]	High [Necessary soon]	High [Necessary soon]	High [Necessary soon]

Appendix 7.9: QFD matrix (Stitching operation study)

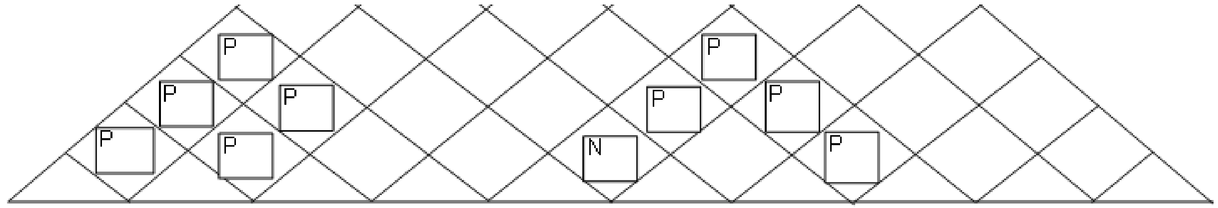


	Different tooling for different job requirments	Changing the grip on the tool, one standard tool with different grip options	Reduce the weight of the tool and using lighter materials	Fit to the individual hand	Size and shape of the tool/handle	Make tool universal for all operators	Hollow structure and composite materials		Sol 9	Sol 10	**Observations and measurements (Force, posture, Repetition etc.)**
Need suitable grip for comfort	Equipment: changing grip on tools to increase comfort. Possible variety of tooling to increase comfort during different operations.	Equipment: changing grip on tools to increase comfort. Possbile one grip which can be attached to several tool handles	Equipment: Reduce the weight of the handle/grip and the tool by using lighter materials	Equipment: TOOL HANDLE RESEARCH, individual preferances. Wrist orientation/position etc	Equipment: TOOL HANDLE RESEARCH, individual preferances. Wrist orientation/position etc	Equipment:Standardised tooling. RESEARCH. Deforming material, same tooling, fits to the individual hand which is using. What oeprators want, what the complany want. PRIORITY SOLUTION	Equipment: Reduces weight and effort required to use. Hollow structure with cover on the tool, reduces heat transfer and makes the tool lighter.				REBA information insert, handle size and weight. Compare with recommended handle/tool weights
Ability to personalise the tools				Equipment: TOOL HANDLE RESEARCH, individual preferances. Wrist orientation/position etc	Equipment: TOOL HANDLE RESEARCH, individual preferances. Wrist orientation/position etc						
Risk or user requirement 4											
Risk or user requirement 5											
Standards, guidelines and regulations				Look up standards and guidelines	Look up standards and guidelines						

Appendix 7.10: QFD matrix (Pipe installation study)

	Install some internal features before wingbox is closed	Install some internal features before wingbox is closed	Change shape of opening to reduce sharp edges	Find alternative means of access	Develop set sequence of moves to enable common approach and opportunity to train in safe facility	Do as much pre-work before entering working area	Explore alternative fixing methods or tools	Observations and measurements (Force, posture, repetition etc.)
Need to adopt awkward posture to reach working area	Equipment: this is not possible with the current design, but can be incorporated in future designs				Better understanding of body capabilities and how to recognise start of error	Will not prevent posture but may reduce time spent in posture	May reduce time spent in awkward posture	Internal access requires unnatural bending at waist and neck with unsupported back
Need to climb through restricted opening	Equipment: this is not possible with the current design, but can be incorporated in future designs	Equipment: may restrict ability to reach other areas	Equipment: this is not possible with the current design, but can be incorporated in future designs	All access routes are restricted	Develop training and publish guidelins on specific means of access for the most awkward areas (e.g. Only one way to get in and out of swiss cheese area)	Will not prevent posture but may reduce time spent in posture	Will not prevent posture but may reduce time spent in posture	Size and orientation of manhole impacts on body structure
No clear view of working area								Are obstructed by other components
0								Tools / equipment not easy to handle within structure and in such postures
Standards, guidelines and regulations								

Appendix 7.11: QFD matrix (Material loading study)



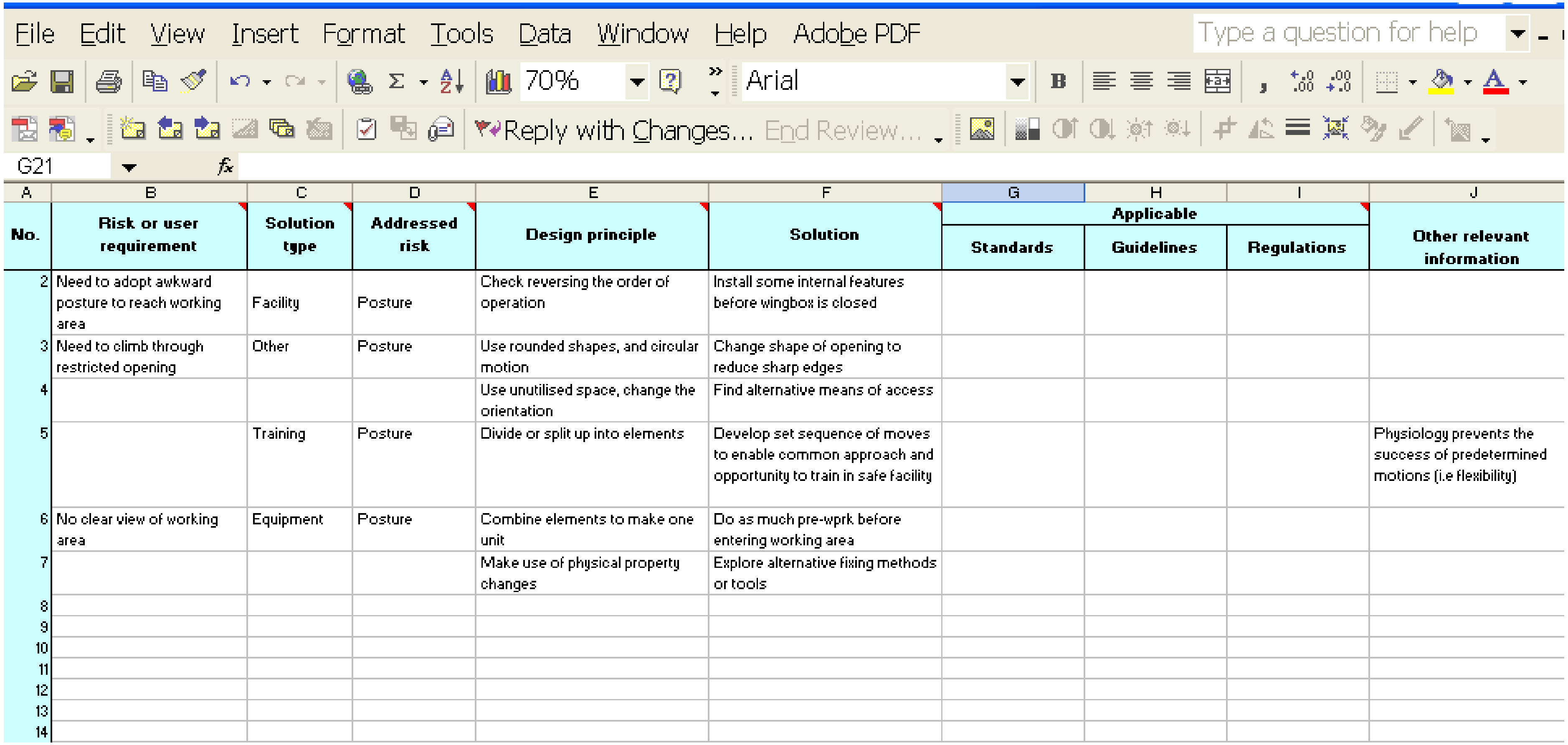
	Automatically timed feeding tube from the premix to the banbury eliminating the repetitive nature of the work over a length of a shift.	Installing a mechanical tilt mechanicm to help with the premix into the banbury via the bucket.	Use of hydrolics to assist in the lifting of the banbury buckets by use of button or lever.	Use of Vaccum pack process to reduce the amount of manual handling by packing the premix which can be utilised by the machine.	Change in dimensions of the bucket in order to reach the bottom with no strain on the lower back or abdominals.	Install a tilting mechanism to make reaching into the bucket easier with no strain on body parts.	Installing a spring loaded mechanism into the bins to rise and drop depending on the weight.	Utilisation of vaccum mechanism to lift the material from the bins.	**Observations and measurements (Force, posture, Repetition etc.)**
Provide Mechanical assistance to help push and tip the premix into the banbury	Fairly expensive to install however will drastically reduce the chances of developing MSD's.	Develop a split table to enable the product to be delivered into the banbury.	Develop or purchase a stock product to enable the split table to work effectively which will in turn reduce work strain.	Buy in bulk, cheap disposable bags for example to pack the premix.					Force of 60 kg weight when pushing and tipping into the banbury throat. This can be repetitive for the duration of the shift.
Reduce the need to reach into the bottom of the banbury bins.					Trial new bins in different sizes to see themost effective sized bin.	Develop or purchase a tilting mechanism from an external company to enable the bins to flow easier with reduced strain.	Developing or installing a spring based mechanism, either within the company or externally with a low coast to the company.	Have an external Company trial a vacoum to lit the materials from the bin and observe to see the effectiveness of this. Cost effective suggestion.	Poor posture whilst reaching into thwe banbury bins, meaning the incorrect bending and lifting technique.
Standards, guidelines and regulations									

Appendix 7.12: Microsoft® Excel-based solutions database (Stitching operation study)

Microsoft Excel - 7 Solution database

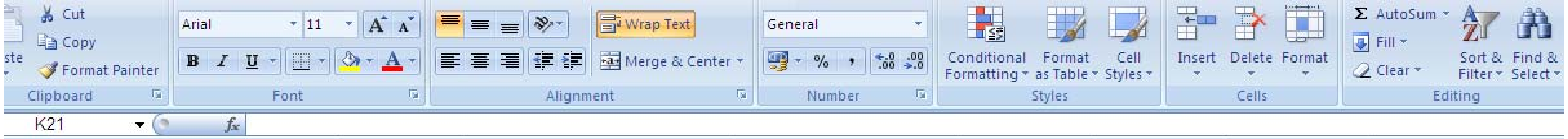
No.	Risk or user requirement	Solution type	Addressed risk	Design principle	Solution	Applicable Standards	Applicable Guidelines	Applicable Regulations	Other relevant information
2	Need suitable grip for comfort	Equipment	Force (load)	Divide or split up into elements	Different tooling for different job requirments		Research		
3	Need suitable grip for comfort	Equipment	Force (load)	Make elements versatile	Changing the grip on the tool, one standard tool with different grip options		Research		
4	Need suitable grip for comfort	Equipment	Force (load)	Reduce or balance load	Reduce the weight of the tool and using lighter materials		Research		cost/supply etc/ cost and benefit...
5	Need suitable grip for comfort	Equipment	Force (load)	Use rounded shapes, and circular motion	Fit to the individual hand		Research		
6	Need suitable grip for comfort	Equipment	Force (load)	Use rounded shapes, and circular motion	Size and shape of the tool/handle		Research		
7	Need suitable grip for comfort	Equipment	Force (load)	Increase adaptability to suit the conditions	Make tool universal for all operators		Research		
8	Need suitable grip for comfort	Equipment	Force (load)	Use flexible and hollow structures rather than solid structures	Hollow structure and composite materials		Research		
9	Ability to personalise the tools	Equipment	Force (load)	Use rounded shapes, and circular motion	Fit to the individual hand				
10	Ability to personalise the tools	Equipment	Force (load)	Use rounded shapes, and circular motion	Size and shape of the tool/handle				
11									
12									
13									

Appendix 7.13: Microsoft® Excel-based solutions database (Pipe installation study)



A	B	C	D	E	F	G	H	I	J
No.	Risk or user requirement	Solution type	Addressed risk	Design principle	Solution	Applicable			Other relevant information
						Standards	Guidelines	Regulations	
2	Need to adopt awkward posture to reach working area	Facility	Posture	Check reversing the order of operation	Install some internal features before wingbox is closed				
3	Need to climb through restricted opening	Other	Posture	Use rounded shapes, and circular motion	Change shape of opening to reduce sharp edges				
4				Use unutilised space, change the orientation	Find alternative means of access				
5		Training	Posture	Divide or split up into elements	Develop set sequence of moves to enable common approach and opportunity to train in safe facility				Physiology prevents the success of predetermined motions (i.e flexibility)
6	No clear view of working area	Equipment	Posture	Combine elements to make one unit	Do as much pre-wprk before entering working area				
7				Make use of physical property changes	Explore alternative fixing methods or tools				
8									
9									
10									
11									
12									
13									
14									

Appendix 7.14: Microsoft® Excel-based solutions database (Material loading study)



No.	Risk or user requirement	Solution type	Addressed risk	Design principle	Solution	Applicable: Standards	Applicable: Guidelines	Applicable: Regulations	Other relevant information
2									
3	Provide Mechanical assistance to help push and tip the premix into the banbury.	Equipment	Force (load)	Combine elements to make one unit	Automatically timed feeding tube from the premix to the banbury eliminating the repetitive nature of the work over a length of a shift.		HSE Guidelines on exposure limits: If this would be under the limits, it would be a good approach.		
4	Provide Mechanical assistance to help push and tip the premix into the banbury.	Procedure	Force (load)	Replace mechanical actions with other physical actions	Installing a mechanical tilt mechanism to help with the premix into the banbury via the bucket.		HSE		
5	Provide Mechanical assistance to help push and tip the premix into the banbury.	Procedure	Force (load)	Use the properties of gas and liquid	Use of hydrolics to assist in the lifting of the banbury buckets by use of button or lever.		HSE		
6	Provide Mechanical assistance to help push and tip the premix into the banbury.	Equipment	Posture	Use cheap disposable copies	Use of Vaccum pack process to reduce the amount of manual handling by packing the premix which can be utilised by the machine.		HSE		
7	Reduce the need to reach into the bottom of the banbury bins.	Equipment	Posture	Use unutilised space, change the orientation	Change in dimensions of the bucket in order to reach the bottom with no strain on the lower back or abdominals.		HSE		
8	Reduce the need to reach into the bottom of the banbury bins.	Procedure	Posture	Use rounded shapes, and circular motion	Install a tilting mechanism to make reaching into the bucket easier with no strain on body parts.		HSE		
9	Reduce the need to reach into the bottom of the banbury bins.	Equipment	Posture	Take counter measures for anticipated issues	Installing a spring loaded mechanism into the bins to rise and drop depending on the weight.		HSE		
10	Reduce the need to reach	Equipment	Posture	Use the properties of gas and liquid	Utilisation of vaccum		HSE		

Appendix 8.1: Email sent by the ergonomist requesting further assistance

Sent: Mon 15/03/2010 09:09
To: Himan Punchihewa

Himan,

How are you?

I have my objectives for this year and have incorporated the tooling design for RH tooling into my plan. Are you still interested in carry out this research and for me to use your methodology? This would be very helpful for me, please get back to me and let me know and we can start to arrange some meetings to get the project continued!

Apologies if I do not respond straight away I am away on a course for the next 3 days but will get back to you on my return

Regards,

A

A
Ergonomist & Bib Standard Facilitator

Message Classification: D3

A - Building 114
ABC Limited Company

Appendix 8.2: Evaluation of the tool sent by the industrial engineer

Sent: Thu 20/08/2009 10:32
To: Himan Punchihewa

Dear Himan,

As a means of review I used the pack as presented to gauge the success and probable adoption of such a technique. I did not significantly adapt the structure of the pack but am aware that this is possible, as already advised, and have made comments where the feedback from the sessions suggested this would be required.

Interview Guide.
For our environment this was too long and required a lot of guidance for us to gain any valuable information. This is partly due to the nature and culture of the workforce where allocation of time is primarily related to production. I would adapt this to a more directed questionnaire focusing on the specific area of investigation. I guess this would require some preliminary investigation work by the person developing the interview / questionnaire and could include informal questioning as part of it.

Observations Pro-forma
The elements are technically termed so may not be fully appreciated by untrained ergonomists. However, if used in conjunction with the REBA pro-forma this is a valuable feature of the pack.
This would need to be developed for our environment, as there are a number of tasks carried out in inclined positions that are not ‘obvious’ in the current assessment format. Recognising that this is only one tool it may be useful to include a matrix advising what tools can be used in different environments?
Translating the information from the interview pack to the spreadsheet was time consuming and required some ‘interpretation’ and application of perception to ‘match’ responses. However, once complete it enabled the Pareto analysis to be formed and subsequently set the priority for review. This was a great way to show the group members that their experience and thoughts about the task were similar and therefore valid to facilitate improvements and gain buy-in to the pack and approach being used.

Solution database
This was probably the best feature of the pack for me as it provided a structured approach to analysing and generating ideas. A large proportion of the time was spent discussing the various design principle as individual understanding of them was varied and initially we were using virtually all of them to develop and understand the issues identified and as means of generating ideas. This focus on specific design features, though, did appeal to both technical and non-technical participants. The engineers considered it to be a very useful breakdown that gave a practical design approach without specific focus on the health aspects (normally associated with ergonomics at our facility). Non-technical members needed more explanation and time to develop their understanding but were more open to the suggestions made in the spreadsheet.

QFD matrix
The approach taken to complete this initially was as a group but it became too confusing and so an off-line translation was carried out based on previous discussions and used as the starting point for development. No one in the group had used this type of analysis before so deciding on the positive and negative interactions took time and led to some misunderstanding at times. The format of this and the solution database allowed each solution to be explored before being discounted due to ‘other’ issues and in some instances strengthened the case for developing a solution further, despite perceived difficulties.
Overall, I think the pack provides a structure for analysing tasks that incorporates engineering and ergonomic practices but that requires a dedication to establish the fundamentals and expand the knowledge database for future development. The pack allowed the presentation and development of numerous ideas and enabled all views to be recorded but there was a need to manage the different aspects of the pack to ensure understanding and minimise bias.
I would like to see the tool developed to be more interactive as the work required to develop and transfer / translate data is time consuming and reliant on the professional approach of the people involved. The pack will take time to establish as a functional and reliable tool but has the ability to be adopted into the engineering toolbox with further refinement.

Kind Regards,

B
Industrial Engineer & Ergonomist
XYZ Ltd.